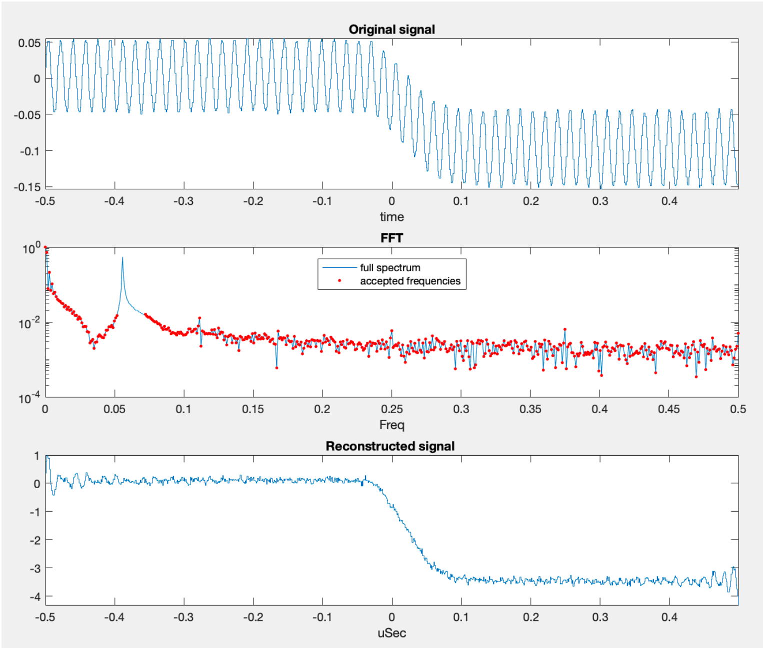
Practical 6: Troubleshooting detector systems

Part 1: SmartPET

The SmartPET detector system has been developed for small animal PET imaging. It consists of 2 planar double sided strip detectors (DSSDs). Each of these are 60x60 mm germanium detectors and are segmented on each side with 12 strips. The strips on opposing faces are orthogonal to each other, effectively giving 144 voxels per detector from 24 strips. The signals from each strip are coupled to individual preamps mounted inside the preamp housing around the vacuum cryostat housing the germanium crystal. Each preamp signal exists the preamp housing via SMA connectors that connect to cables that run along the top of the liquid nitrogen Dewar to a endplate when the connections can be easily accessed. The bias shut down is signal is also mounted to this plate. The preamp power and high voltage are input directly to the preamp housing.

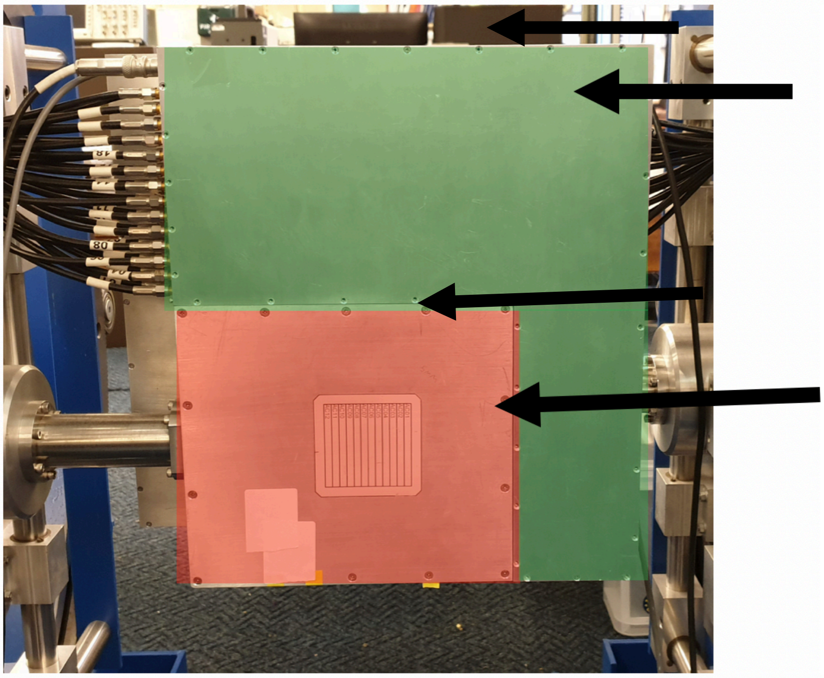
Ensure that the detector is powered up and has HV applied (ask a demonstrator for confirmation) .
Connect one of the Preamp signals to the large oscilloscope. Note the dominant features of the signal you observe.
Check serval different channels
Check two signals from the AC side of the detector, compare the frequency
Check two signals from the DC side of the detector, compare the frequency
Use the oscilloscope's inbuilt Math mode to create an FFT of one of the preamplifier signal. Note the dominant frequency.
Switch off the FFT
Adjust the oscilloscope's time scale to be 100ns per division
Save a trace to a USB stick as a csv file.
Ask the demonstrator to power down the HV and turn off preamp power.

As the observed noise is highly regular, an FFT can be used to remove the unwanted high frequency noise. A simple Matlab code is shown to do this.
Load the saved preamp trace on the laptop and save it in a folder on the desktop called 'NuSPIN'.
Open the csv file and remove the first 2 lines so that only the sample data is shown.
Open the file fft_dan_5mm.m in Matlab (this should already be open)
Change the name of the file in in the 'load' statement and the following 2 lines to match the name of your saved scope trace.
Run the Matlab code.
This should show 3 plots. The 1st is the original trace from the oscilloscope. The second is the FFT of this signal. The red points show the data used to create the bottom plot. The bottom plot shows the inverse FFT of the red points shown in the middle plot. A simple gate allows you to reject unwanted frequencies. This is shown in the image below.



At the top of the Matlab code is a parameter called 'gate' adjust this to make sure that the strongest frequency peak is not included in the inverse FFT.

Once the SmartPET detector has been power off for a few minutes, remove the preamp housing cover – NOT THE CRYOSTAT COVER. See image below.



Remove this

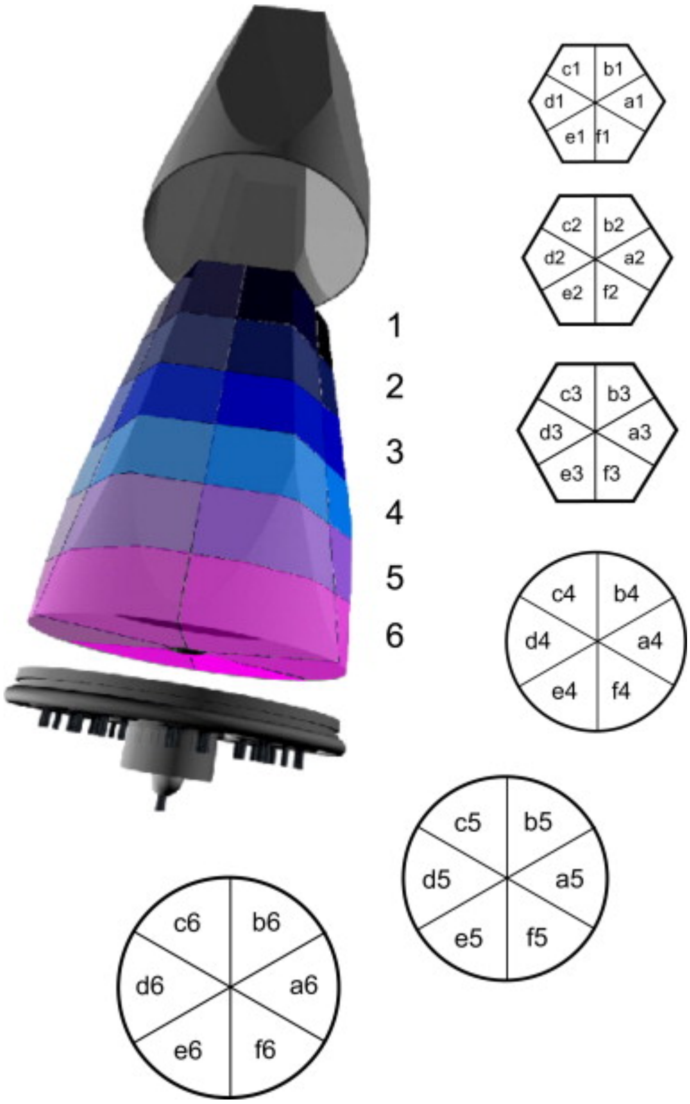
DO NOT remove this

Identify the preamps, HV filtering and bias shutdown circuits.
Inspect the preamps and make sure none are loose, incorrectly seated etc.
Identify any loose wiring
Correct any identified issues.
Once this has been completed, replace the preamp housing cover. Turn on the preamp power. Connect one AC channel and one DC channel to the oscilloscope.
Look at each signal whilst SLOWLY increasing the bias voltage up to it's maximum of 300V. Apply around 50V at a time and wait for the preamp signals to stabilise before increasing again. Sensible signals may not be seen until the detector approaches depletion.
Confirm that the signals look ok.

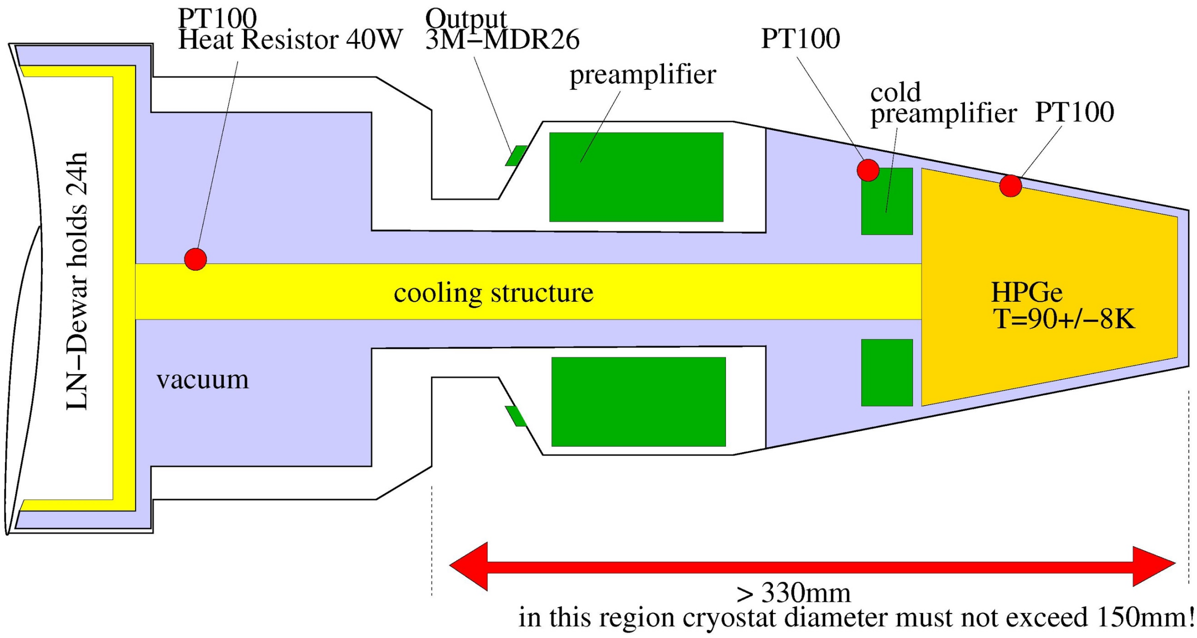
<u>Part 2: Agata</u>

Agata is a project to develop a 4Pi array of germanium detectors for nuclear structure studies. The full array will consist of 180 detector capsules each of which is segmented into 6 rings, each with 6 sectors giving a total of 36 segments (and a full volume core signal) per detector. The rings are numbered 1-6, which 1 being at the front of the detector and each sector is labelled A – F.

Each germanium crystal is encapsulated in a ultra high vacuum aluminium capsule for ease of handling. This is shown in the figure on the following page.



Each capsule is delivered by the manufacturer (Mirion - Canberra) in a bare state and must be assembled into a cryostat before use. The capsules are first built into a test cryostat and undergo Customer Acceptance Testing (CAT) to ensure that they meet the agreed minimum specification before being installed into either a double or triple cryostat and assembled into the array. The layout of the test cryostat is shown on the following page.

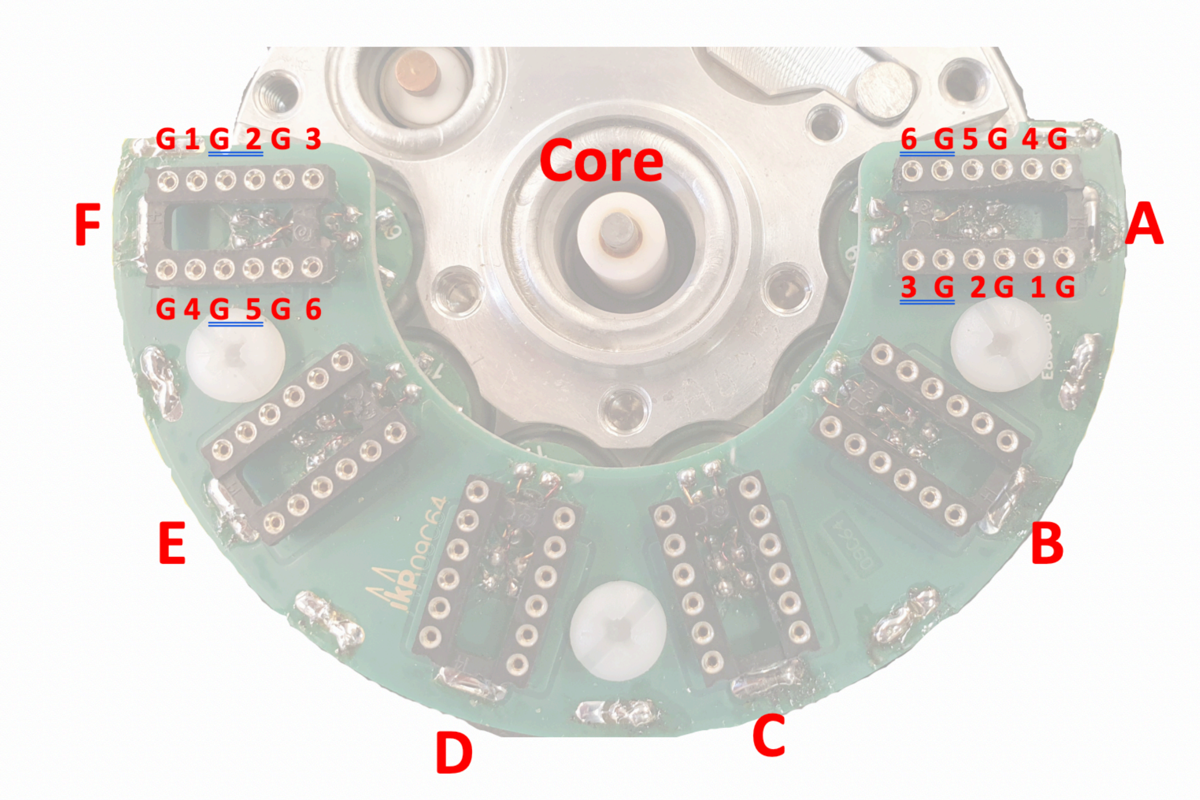


Before the capsule is assembled and built into a cryostat, it is important to check that the internal wiring of the capsule is intact and correct. This is done by measuring the resistances of the segments. There are 2 measurements that can be made. The 1st is to measure the resistance through the germanium crystal from a segment contact to the core contact (through the bulk of the crystal). All segments should have a similar resistance of ~15-30 Ohms. If the measured values are significantly outside of this range, it is possible that the wiring inside the capsule has been damaged (e.g. during shipping etc.) The 2nd set of measurements are the inter-segment resistances (e.g. A1- A2, A1-A3 etc.) This can be used to check that there is not a short circuit between adjacent segments and can be used to confirm that the internal wiring is connected in the correct order. For example the resistance between segment 1 and segment 2 should be less than the resistance between segment 1 and segment 3 as segment 1 is physically closer to segment 2 than segment 3.

In the following image, the 6 connectors located on the PCB corresponds to segments A-F and each connector has pins for segment 1-6 as well as 6 ground pins (labelled G).

Measure the resistance between segments to the core and note any that are significantly outside the range ~ 15-30 Ohms.
Note: When measuring the resistances, the meter is injecting a small current through the crystal, from which it calculates the resistance. Therefore, when checking the resistance DO NOT measure for a long time (more than a couple of seconds)

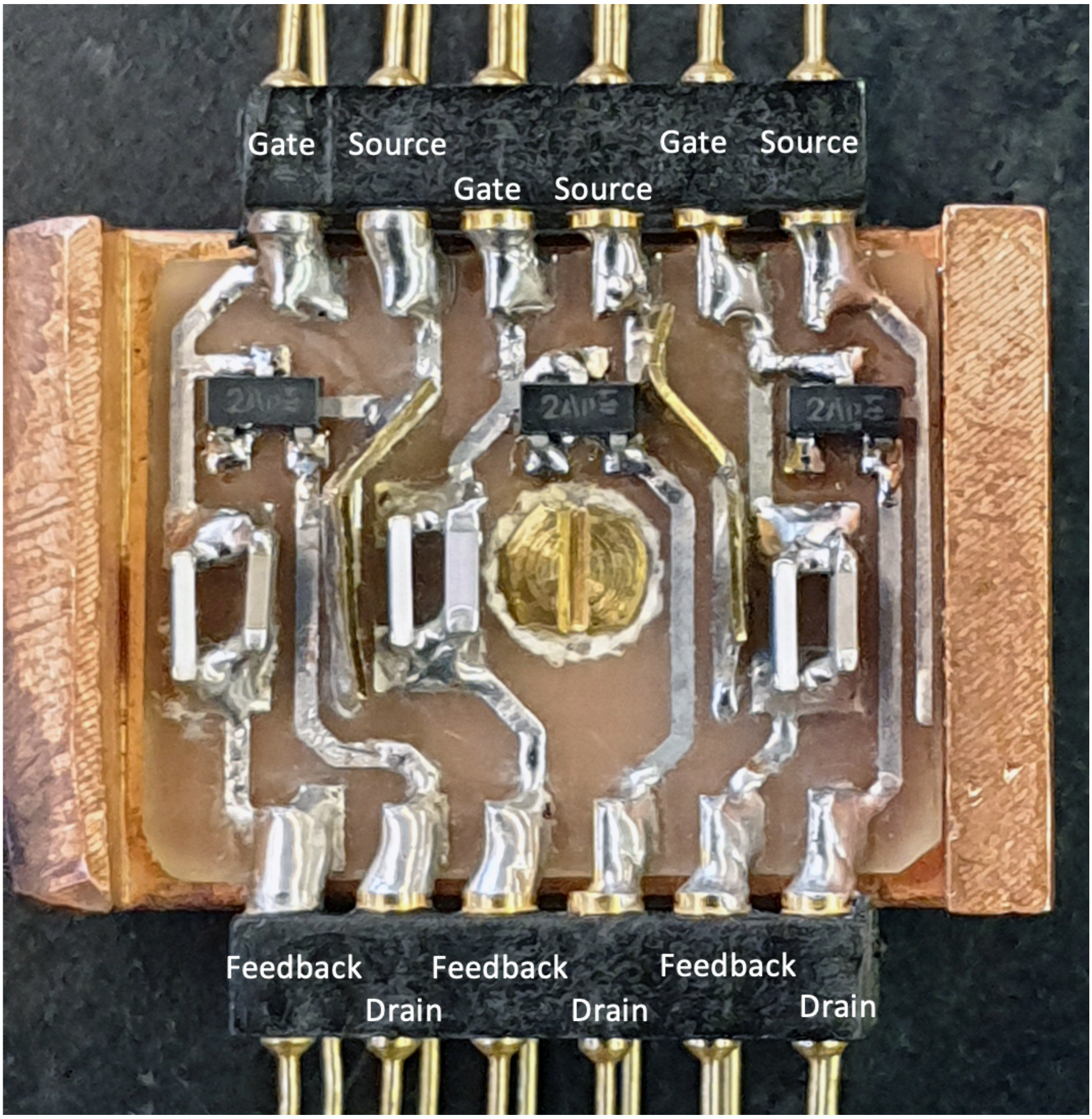
Measure the resistance between pin A1 to A2, A1 to A3, A1 to A4, A1-A5 and A1-A6 and confirm that they are in the correct order.



A copper block is mounted on to each of the 6 connectors. This contains a cold-FET which is the first stage of the pre-amplification. Each copper block contains 6 FETs, 1 for each segment. A close-up of the FET is shown in the following image. In practice, these FET blocks are housed in a copper jacket to help shield them from stray electrical signals and help reduce cross-talk. One of the most common failure modes for a germanium detector is for this FET to fail. This can happen due to incorrect bias voltage, applying bias while the detector is warm or allowing the detector to warm up while under bias or mechanical vibration / shock. The FET failing will usually result in a DC offset of ~1V on the preamp signal and no detector signal being observed.

It is possible to measure the resistance at various points to check if the FET is damaged. Shorting the 'Drain' and 'Feedback' pins together and measuring the resistance to the 'Source' pin should give a resistance of around 30 Ohms. Shorting the 'Drain' and 'Feedback' pins together and measuring the resistance to the 'Gate' should give a resistance in the mega-Ohms range. If the measured resistances are outside these ranges, the FET should be replaced.

Measure the 'Source' to 'Drain'-shorted-with-'Feedback' and 'Drain'-shorted-with-'Feedback' to 'Gate' resistances for the unshielded FET block and check they are within spec.



The ‘Feedback’ and ‘Drain’ pins from the FET block are connected via thin wires to feedthroughs on the cryostat which pass the signal to the ‘warm’ preamp boards mounted below the endcap. Each segment preamp board contains 3 individual preamps, so one sector, has 2 preamp cards. The preamps give a differential output signal which is used to reduce the noise on the signal. If the preamp output is to be used in conjunction with standard electronics that require a unipolar signal, a NIM converter box can be used.

The signal from the core contact is also processed in the same way, using a similar circuit to the segments but an additional decoupling capacitor is included in the cold FET stage due to the core being AC coupled.

The core preamp can accept an input from a pulser signal which can be used to test the electronics. As there is currently no capsule attached to the cryostat, the effect of the RC differentiation circuit will clearly be seen.

Connect the pulser to the oscilloscope and set the output to be a square wave with a frequency of 300 Hz and an amplitude of 100 mV (this should already be set). Ensure that the endcap is on the Agata cryostat and the NIM crate is powered off.
Connect the pulser to the Agata Test box and ensure that this is connected to the core preamp board. Connect the bottom BNC connector of the CWCS-I/O converter box (in the NIM crate) to the oscilloscope. Power up the NIM crate and the effect of the RC differentiation circuit should be seen. Compare the input signal to the output signal.

While looking at the signal on the oscilloscope, carefully lift the endcap directly up, off the top off the cryostat, being careful not to disturb any of the internal electronics.
Note the effect of the end cap on the observed signal. Compare the magnitude of the signal to that of the signal with the endcap in place.

Carefully, without touching the electronics, move your hand close to the copper block and notice the effect on the signal. This demonstrates how sensitive the electronics are to stray fields and varying capacitance you your hand acts as a ground plate.

Power off the NIM crate to remove preamp power.

The braided copper connectors are screwed to the FET blocks and allow them to be cooled to near liquid nitrogen temperatures. The capsule is screwed to the large copper cold finger for cooling. A PT100 is attached to the capsule to allow the temperature to be monitored. While cooling the detector it is important to measure the PT100 resistance as a function of time. This information can give an indication of the level of vacuum inside the cryostat. A poor vacuum will mean that the detector takes longer to cool and if the vacuum is really poor, it may not be possible to cool the detector to the required temperature.