Operating manual of the upgraded NIKHEF characterization station for prototype solid state detectors

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June 2005
Overview of the upgraded characterisation station
1 Hardware
1.1 Preamplifier

The first stage of the preamp circuit is formed by the Amptek A250 integrating amplifier with the 2SK152 Nchannel FET mounted onto the PC250 board. From the noise performance curves given by Amptek this FET seems to be the best solution for small capacity detectors. The FET is possibly made by Sony. I could only find a simple datasheet with few numbers on it, no performance figures. If anyone finds a better FET, please tell me. Since the FET has no input protection, it is easily damaged. But on the other hand it is cheap and can easily be replaced as it is mounted on socket buses on the PC250 board.

The preamp transfers the charge signal of the test detector into the 1 pF internal feedback capacitor of the A250. One would thus expect a sensitivity of 1V/pC as is specified by Amptek. However, I rather measured about 0.75 V/pF, an indication that parasitic capacities may play a role as well. The decay time of the A250 circuit is expected to be 300 µs.

Subsequently the signal is shaped while its baseline is stabilized on the second stage of the preamp circuit that is mounted on the PC275 board. This is done by two A275 shaper hybrids and a baseline restore hybrid BLR1. The first A275 hybrid gives the falling edge of the step signal from the A250 an exponential decay with a time constant of 0.85 µs as is given by the high pass circuit formed by C1 and R1. In addition it provides a gain of 10 that follows from

\[ G_1 = \frac{R_4 + R_5}{R_5} \]

The second A275 hybrid slows down the steep rising edge to a rise time of about 1 µs by the low pass circuit of L2, R2 and C2. This stage has gain between 4 and 10 that is controlled by potentiometer R12. It is advised to
adjust the gain to the maximum. Finally the BLR1 gives a LF feedback to the -
input of the first A275 via jumper J3. Since this is done by an internal 10k resistor
that is well AC coupled to ground, the gain of the first A275 is increased by 10%.
I had to add a large filter capacitor C4 (10 µF) to avoid increase of the noise level
and instability in the output pulse.

### 1.2 Bias voltage filtering

The bias voltage across the sample is filtered in the preamp box by a low pass
filter formed by C12 (10 nF) and R4 (100MΩ) with a time constant of 1 s.
However, if we would connect the test detector directly to this filter then
in case of a discharge across the sample the full charge of C12 would
be transferred into the FET input that would certainly destroy it. Therefore
a second low pass filter is added formed by R7 and C15. C15 is the
 capacitor between R7 (detector HV connection) and the ground. The
 unused ground bus of Q1 is used for this. C15 is not drawn on the Amptek
 schematic although it is certainly needed. Note that a low value of C15 diminishes
the charge signal according to

\[ Q_m = Q \cdot \frac{C_{15}}{C_{15} + C_{\text{det}}} \]

where Q is the real charge, \( Q_m \) is the measured charge and \( C_{\text{det}} \) is the capacity of
the test detector. The present value of 47pF for C15 applies well for low capacity
test detectors. But especially for detectors with an unknown or fluctuating
capacity it is better to increase C15 at the cost of a higher risk on damaging the
input stage. However in most cases a discharge will only destroy the inexpensive
input FET.

### 1.3 Bias voltage current circuit

The values of the default bias voltage circuit are optimised for bias currents up to
a few nA. For higher bias currents the bias voltage across the sample will deviate
considerably from the bias voltage that is set by the HVPS control. The
schematic shows that for the default values the total resistance of the bias voltage
connections amounts 1.3 GΩ, so a bias current of 10 nA reduces the actual bias
voltage across the sample by 13 V. In general it is favourable to use a high-ohmic
bias voltage circuit since it protects the sample by a hard limit on the shortcut
current. But for currents exceeding a few nA it is better to reduce the resistance of
the bias voltage circuitry.

The most obvious resistor to reduce at first is R1 on the main PCB in the preamp
box, such at the cost of an increased noise level. It is recommended to modify R2
to the same value as well. A value of 3M3 is known to give a very bad noise
behaviour, but a value like 100M is probably still acceptable. This will reduce the
resistance of the bias voltage circuit to 400 MΩ. In combination with a reduction
of R4 and R7 on the PC250 board to 10MΩ each we get 220MΩ, enabling
operation until 100 nA. For higher bias currents we also have to reduce the value
of the current sense resistor R7 on the main PCB. Again to avoid false current
readings it is wise to reduce the guard current sense resistor R5 to the same value.
To avoid false current readings when starting the measurement the reference resistors R6 and R4 should also get the same value as R7 and R5.

1.4 Connecting the sample to the sample PCB
Drill a hole in the centre of the sample PCB leaving sufficient surface to attach the sample on. The bias voltage is supplied by the strip that runs until under the sample.

- DC coupled signal electrode. The signal electrode is connected to the S pad. Also the bias current is measured at this connection. The guard connection can be made via the G pad. Select “Ibias from “S” pad” on the CCD6024-upgraded.vi to get the proper bias current reading.
- AC coupled signal electrode. The signal electrode is connected to the S pad. It is recommended to make the bias current (GND point) connection to the G pad. Select “Ibias from “G” pad” on the CCD6024-upgraded.vi to get the proper bias current reading. The leakage current through AC insulation of the electrode is monitored by the “guard current” readings.

1.5 ADC sampling
The 12-bit ADC of the PCI 6024E board in the PC has internally a range of –5V to +5 V. But to accommodate a wider dynamic range, a preamplifier is incorporated onto the board having a gain of either 0.5; 1; 10 and 100. The circuit automatically selects the lowest gain from the input limit values that are set on the 6024E-2.vi window. The default values are +0.4 V and –0.4 V for the high limit and the low limit respectively, yielding a gain of 10 and a least count of 0.2441 mV.

The sampling moment is given by the falling edge of the sample pulse that is triggered by the scintillator. However, the limited bandwidth of the PCI 6024E
preamp broadens the signal pulse that is transferred to the ADC. As the result I had to set the sampling moment at 2.25 µs while the peak of the output pulse from the Amptek preamp occurs at 1.43 µs. The sample pulse is available on the front of the DAQ box. Note that in case the gain of the PCI 6024E board is set to another value than 10, the width of the sample pulse has to be readjusted for the maximum signal amplitude.

1.6 Gain calibration
The calibration of the gain of the whole system including the DAQ is done in the following way. Connect a block generator with a signal of a few volts p-p to the test input of the DAQ box. Also connect an accurate attenuator to this signal. The output of the attenuator has to be directed via an oscilloscope (high impedance input) to the test pulse input of the preamplifier box. Set the attenuator and block pulse generator such that the test pulse to the preamp box is a few mV p-p at a frequency of 50 – 100 Hz. Measure the p-p amplitude of the test signal to the preamp box with the oscilloscope.

Both the rising and the falling edge of the test pulse are converted by the calibration capacitor C9 into a positive and negative charge signal to the preamplifier. I removed the factory-provided C9 and replaced it by a more robust calibrated capacitor with a nominal value of 2.2 pF. To this value one still has to add the value of the parasitic capacity of the traces on the board. I have measured this value as 0.11 pF. A label with the calibrated value is glued on the PC250 board. The charge of the test pulse follows from \( Q(e^-) = A \cdot (C_T + C_P) \cdot V_T \) where \( Q(e^-) \) is the input charge expressed in number of electrons, A is a constant (6241), \( C_T \) is the calibrated test capacitor in pF, \( C_P \) is the parasitic capacity in pF (0.11 pF), and \( V_T \) is the step height of the test pulse in mV. The physical calibration of the whole system follows from \( G = \frac{Q(e^-)}{V_m} \) where G is the gain of the system and \( V_m \) the signal voltage measured by the DAQ. As an example, when the gain adjustment by R12 on the PC275 board was set to maximum, I measured \( G = 242 \) e^-/mV.

1.7 Noise and pedestal calibration
Noise calibration can be made without additional equipment. On the Meas6024E.vi window, set the clock source to “internal” and the scan rate to 50 – 100 Hz. The test pulse input of the preamplifier box should be open. Run the VI for at least 2000 events. The noise and pedestal values are given in the top of the histogram\(^1\). I measured without a detector a value of 0.86 mV (208 e^-). The figure is increased by the detector capacity according to 4.6 e^-/pF. Note that the noise figure can be lowered by about 10 e^- if C9 is removed when the system is not being calibrated.

Do not forget to change the settings of the Meas6024E.vi window back to default afterwards.

1.8 Collimator and scintillator
The collimator is formed by a plastic house to minimize Bremstrahlung events. In

\(^1\) Note: these values are directly calculated from the data and do not depend on the histogram settings.
addition to get the best confinement a cap is screwed onto it that is made from a W/Cu 72/18 alloy having an aperture with a width of 0.6 mm². As a result a well-confined beam is obtained. The 3 mm wide scintillator block is positioned 9.5 mm under the collimator.

The assembly of collimator and scintillator is adjustable in X and Y by two micrometer screws. The Z adjustment screw has no metering scale. However, it is still well possible to make a reasonable accurate displacement by turning the adjustment knob with a 2 mm Allen key. The pitch of screw is 0.3175 but note the dead course of about 120°.

Aligning the collimator to certain spot on the sample is done best in the following way.

1. After the sample has been attached on the C-board the Perspex collimator plate is mounted again.
2. Unscrew the tungsten cap from the plastic collimator part and put the plastic part in the collimator plate.
3. Align the collimator in X and Y when looking straight through the 3 mm wide channel in the collimator. It is practical to use the miniature torch for better illumination.
4. Adjust the Z stage to a high position, remount the tungsten cap and put the collimator back again. Take care that the scintillator does not touch the sample board. It is often possible to check and realign the collimator when looking through the pinhole of the tungsten cap.
5. Adjust the collimator in Z direction when looking from aside.

The Gaussian width of the particle beam at distance of 0.15 mm between collimator and sample was measured as 0.167 +/- 0.019 mm. The plotted measurement is the derivative of the S-curve obtained when scanning the collimator to the edge of a 1mm thick tantalum plate. The measurement shows that all tracks remain well within a circle of 1 mm diameter. The beam has a fairly good parallelism; at a distance of 3.33

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2 Other apertures from 0.4 mm on are available on request.
mm the width has increased to 0.23 +/- 0.2 mm. From a 50 µCi (1.85 MBq) $^{90}$Sr source I obtained without sample a trigger rate of about 90 Hz. For this measurement the scintillator was operating at its plateau. With a 280 µm silicon detector added the trigger rate was reduced to 37 Hz at 5 mm collimator-to-sample distance and 17 Hz at 0.1 mm distance to the sample. The lower trigger rate at a small sample distance is caused by multiple scattering at the sample. When the collimator is close to the sample, the path length between sample and scintillator is automatically bigger so the multiple scattering by the sample has more effect.

1.9 Scintillator
The scintillator is formed by a 3 mm wide and 3 mm long cylinder of scintillator plastic. It is coupled via a 22 mm long light guide to a Hamamatsu H5783 photomultiplier. Because of the small scintillator dimensions in combination with the short light guide a high efficiency is obtained in combination with a negligible dark count rate$^3$.

1.10 Temperature control
The temperature of the sample can be regulated by an air stream that is passing the air temperature block. The block is mounted on a Peltier cooler enabling a wide temperature range both below and above room temperature. The polarity of the current determines whether temperatures lower or higher than environmental temperature can be obtained. The air is directed through a channel in the air temperature block to the sample. The sample board carrying the sample is mounted on the C interface board. The C board is mounted on 6 stainless steel capillaries to provide a good thermal insulation to the main board. As a result the sample temperature can be efficiently regulated by the air from the air temperature block.

To set the temperature to another level than the environmental temperature first switch on the air circulation pump$^4$. Note that the circulation air enters the preamp box via the lower air connection and leaves it via the upper connection. Once the Peltier current is set it takes about 30 min before equilibrium is reached. The temperature is monitored by three sensor elements: a Sensirion SHT75 sensor that measures the temperature and relative humidity of the air temperature block and two thermistors that are mounted on the sample board upstream and downstream in the airflow along the sample. The sample temperature is assumed to be the average of both thermistors. The reading of all sensors can be observed

$^3$ Of the order of 1 count per minute, possibly caused by cosmosics.

$^4$ Beware: removing the tube connectors of the circulation air on the DAQ box automatically blocks the airflow to and from the pump. This should never happen when the pump is running since it will damage the pump.
by running Thermistor plot.vi.

To avoid condensation when cooling down dry gas (dry air, nitrogen, …) has to be provided. A fitting for 6 x 0.8 mm plastic tubing has been provided. The internal valve has been adjusted at a flow of 20 l/h at 1 bar gauge input pressure.

The lowest sample temperature I obtained was –2.5 °C at 3.34A Peltier current and 22 °C lab temperature. Thermistor 1 was 3.6 °C colder than thermistor 2. Note that the collimator should have certain distance (about 3 mm) to the sample to avoid disturbing the airflow. On the other hand if the collimator is adjusted too high then the scintillator comes close to the sample board, affecting its temperature. For the rest also the position of the X-Y stages are expected to have certain effect on the sample temperature. The lowest temperature that can be reached depends directly on the environmental temperature. Sample temperatures in the –10 to –20 °C range are expected to be possible if the whole preamp box is put into a cooled climate chamber. However, this has not yet been tried out.

The maximum sample temperature is not determined by the maximum Peltier current but by the heat tolerance of the Peltier and the Sensirion SHT75 sensor. For the Peltier DT12-8 made by Marlow Industries the maximum operating temperature amounts 150 °C but recommended is not to exceed 85 °C. The SHT75 sensor has a measuring range between -40 °C and 123.8 °C. As a compromise, also taking into account the other materials of the temperature control system, I suggest not exceeding an air channel block temperature of 100 °C. At this temperature I obtained 86 °C sample temperature with a difference of 10 °C between both sample thermistors. This was measured at 22 °C environmental temperature and 2.91A Peltier current. Also in this case we can get the sample temperature closer to 100 °C and reduce the temperature difference between both sample thermistors if the environmental temperature is increased in a climate chamber.
2 DAQ
The DAQ is done using <CCD6024-upgraded.vi>. A series of measurement runs is being taken each having their specified bias field and number of events. Initially the directory will be created in which the datafiles will be saved. The directory carries by default the name of the substrate. If such a directory already exists and should not be deleted, then an extension should be made like <-1>, <-2> etc. If the existing directory has to be deleted then it is best to terminate CCD6024E and to delete the directory first. Subsequently the subvi <Runparas.vi> opens a text file containing a list of the measurement series, <VbiasContr.vi> sets the bias voltage to the required value and the measurement starts using <Meas6024E-upgrad.vi>. This vi samples the peak of the preamp pulse in mV. Once finished the data is saved including a preamble containing a number of measurement parameters. The delimiter between preamble and data values is <&&&>.

2.1 CCD6024-upgraded.vi
2.1.1 Values to be inserted before running (yellow fields).
- Characterisation. Select the required characterisation file. This file contains three columns separated by a TAB. The first column gives the required bias field in V/µm, the second column gives the required number of events and the third column gives the name of the datafile under which the data will be saved.
- Substrate. Name of the substrate, to be used for the datafile directory.
- Substrate thickness(um). Insert here the correct value since it is used to calculate the bias voltage.
- Substrate orientation. Describing which side is up. Try to select an appropriate description or insert a description in <comments> (see below).
- Pumped/unpumped. Select the appropriate state.
- Bias current limit (pA). If the absolute value of the bias current exceeds this value, then the DAQ is terminated and the current measurement run is not saved. The vi is immediately terminated if the value of the current limit exceeds the measuring range of the DAQ hardware.
- Source.
- PM voltage (V). The value to which the PM voltage is set. A value between 850 and 950V is recommended.
- Comments. May be used for additional information.
- Histogram limits. Lower and upper limit of the histogram of <Meas6024E-1>. Does not affect the output data.
- R-bias sense (R7) (ohm). Value of R7 and R5 on the main PCB> used to calculate the bias and guard current from the voltage drop across R7 and R5.
- R-Therm (ohm). Value of the thermistor series resistor in the DAQ box. 560 kΩ for the upgraded DAQ box, 510 kΩ for the old version.
- V-Therm (V). Voltage across the thermistor circuit. 6V for the upgraded DAQ box, 5V for the old version.

2.1.2 Output values (blue fields).
- Run parameters. List of all measurements that have to be done.
- Ebias(V/um). Value onto which Ebias is/will be set.
- Preamble on datafile. As an example the preamble of the previous measurement.
2.1.3 Control

- **STOP.** Stop running after the next measurement has been finished.

2.2 Meas6024E-upgrad.vi

Samples the peak of the pulse from the characterisation box. DAQ is done in 'scan series', i.e. a sequence containing a specified number of samples. After each scan series a few checks are done like an Ibias measurement and if the total number of events is attained.

2.2.1 System values (white fields). Do not alter these values unless required.

- **Device.** Set the required number, generally <1>. If it does not work, find the correct value using the 'Measurement and Automation Explorer'.
- **Time limit (s).** If a scan series takes more than this time then the scan is terminated without further error notice.
- **Clock source.** Select for normal running only: “PFI pin, high to low”. Select for free running noise/pedestal measurements: “internal”.
- **Channels.** Analogue input channel (0) to which the preamplifier output from the characterisation box is connected.
- **Scan rate (Hz).** Beware: should be always 0 at normal running. Set to required value (50 – 100 Hz) only for the free running noise/pedestal measurements.
- **Input limits.** The highest absolute value of these limits determines the gain of the internal amplifier of the PCI6024E board. See the table on the panel of the
vi. In principle only values yielding a gain of 10 should be inserted, otherwise the timing of the sample pulse at the DAQ box has to be modified.

- Coupling & input config. Keep on the default settings (“DC” and “differential”). If the signal and ground of the preamplifier output are connected to analogue input channel 0 and 8, then for the <differential> setting only the difference between both inputs is recorded.

2.2.2 Input values (yellow fields)
Histogram parameters. Most values are automatically set if CCD6024E-1.vi is used. Exceptions:
- step (mV). Bin width of the histogram (default 0.5).
- # of scans. Length of a scan series. Taking this value too small makes the measurement slow while for a too big value the checks and current measurements are not done frequently enough.

2.2.3 Control
- STOP. Stop running after the next scan has been finished.
3 Analysis of the data file

The datafile made using <CCD6024-upgraded> is analysed by <Newana2.vi>. The routine creates a histogram and fits a Landau curve through it. The Landau function used to fit the histogram is convoluted with the electronic noise. In addition a pedestal peak is added. We refer to this as "convoluted landau" (red curve). The height of the pedestal peak may be fitted separately.

3.1 Landau fitting function.

For the Landau fit function we start with an empirical approximation given by

\[ L = p_4 \cdot \sqrt{e^{\frac{x - p_1}{b}} - e^{\frac{-x - p_1}{b}}} \]

where \( L \) is the value of the function, \( p_4 \) is a vertical scale factor, \( p_1 \) is the most probable value of the distribution and \( b \) is a measure of the width of the distribution \( (b \approx \text{rms} / \sqrt{2.22}) \). This function is referred as "primary Landau" (blue curve). Note that the primary Landau shows the spectrum we would measure using a noise free electronic chain, so this curve represents the physical output of the sample independently of the characterisation station. Subsequently, the function is convoluted by a Gaussian noise spectrum representing the electronic noise. The resulting curve is referred as "convoluted landau". Finally the curve of the pedestal peak is added to the fitting curve. This curve has the shape of a Gaussian function having a width equal to the electronic noise and is centred on zero. Here only the height is an independent fitting parameter.

The fitting procedure is performed using the Levenberg-Marquardt fitting algorithm. Parameters to be fitted are:

- \( p_4 \) (height parameter of the landau function)
- \( p_1 \) (most probable value of the landau function)
- \( b \) (width parameter of the landau function)
- \( a \) (height of the pedestal peak)

The fitting itself consists of running the program for a number of times while adjusting the pedestal value until the left edge of the fitted curve corresponds well with the histogram. Subsequently the calculated values are stored into the results file by moving the <Store data?> slide.

3.2 Parameters to be inserted by the operator

3.2.1 Data file parameters

- Same/new file
- Same/opp. pol. Since Newana2.vi only analyses positive going signals, select <opp. pol.> to negate the input data. Note that in this case <pedestal> needs to be manually negated as well.
- preamble? Select <NO> is the data file contains no preamble.

3.2.2 Histogram input parameters

- max
- min
- # of bins
- % max. over/underflows. Default value 2%. A red warning panel is shown if the more than the specified fraction of events is located outside the histogram limits.
3.2.3 Select fit function and data manipulation
- Subtr. ped. value from data? Default YES. This function is only active if the Landau fit is selected.
- Y scale factor. Default 1.00. Normally not used anymore.
- Fit selector.

3.2.4 Landau fit input parameters
- fraction(%) of ped. events. This serves as a starting value for the fitting procedure or is used as the best guess for the real fraction of pedestal events, depending on the <fitted/default ped. peak> switch.
- pedestal (mu). Use this input to carefully tune the histogram position such that the left edge of the fitted pedestal curve coincides with the histogram. To do this, zoom in to the histogram by modifying the scale values.
- electronic noise. Insert here the measured sigma of the electronic noise.
- seed values. Normally at <Automatic seed>. Since the Levenberg-Marquardt fitting procedure is very reliable, manually inserting values is seldom necessary.
- fitted/default ped. peak? Choosing <fitted> enables fitting the height of the pedestal peak. If the pedestal peak is badly or not at all visible, then choosing <default> is recommended thus forcing the pedestal height at <fraction(%) of ped. events>.

3.2.5 Landau plot select
- Indicate here which fitting functions have to be displayed, normally all functions are selected.

3.3 Output windows
3.3.1 Output
Fit calculation results. The values listed in the <Gauss/Land.> array apply for...
either the Gaussian fit or the Landau fit.

3.3.2 Gauss parameters

- \( p_4 \) (scale factor). Y scale factor of the fitted Landau, no specific physical meaning, not used for the Gaussian fit.
- \( \sigma \) (left) and \( b \) (var. par.) (right). Sigma of the Gaussian fit and variance parameter \( b \) of the fitted primary Landau fit respectively.
- \( \mu \) (left) and \( p_{1\text{most prob.}} \) (right). Centre of the fitted Gaussian distribution and most probable value of the fitted primary Landau respectively.
- surface(a) (left) and pedestal (%) (right). Surface of the fitted Gaussian and fraction of the fitted Gaussian through the pedestal peak compared to the total surface of the fitted curves respectively.

3.3.3 Landau parameters

- mean prim. Mean value of the fitted primary Landau.
- rms prim. rms value of the fitted primary Landau.
- FWHM prim. FWHM value of the fitted primary Landau.
- mean conv. Mean value of the fitted primary Landau.
- rms conv. rms value of the fitted primary Landau.
- FWHM conv. FWHM value of the fitted primary Landau.
- mse. mse is the chi-squared error between the convoluted Landau and the histogram.

3.3.4 Histogram parameters

- over + underflows(%). Percentage of events that is not included in the histogram.
  3.3.4.1 Parameters within the yellow frame.
  These values are for studying the performance of the sample when connected to a discriminator. The threshold of the discriminator is manually adjusted by dragging the blue cursor <Thresh> in the histogram window.
  - \( \sigma \). The rms of all data values exceeding <Thresh>.
  - mean. The mean of all data values exceeding <Thresh>.
  - eff. conv. L.(%). The fraction of the surface of the curve of the convoluted landau exceeding <Thresh>.
  - lower threshold. The value of the <Thresh> cursor.

3.3.5 Output to file?

- Store data? Save the values shown at <Fit calculation results> to the output file specified in <Path of result file>. Set this switch only if the output data is valid and run again. The switch is reset automatically.
- New/same output file. Creates new result file in spreadsheet format with the appropriate column headers.
- Save curve? One may select either the histogram alone or the histogram + the fitted primary Landau curve. For the <Newconv_xxx> routines one should exclusively select <prim. land. + hist.>. Output format: 1st and 2nd column X and Y of the primary landau respectively, 3rd and 4th column X and Y of the histogram.