Characterisation Procedure for TELLIE PIN diodes

E. Leming (adapted heavily from SNO+-doc-3148-v1)
University of Sussex

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Figure 1: *Please remember to try and stay positive thoughout these tests...*

Introduction

This document details the characterisation procedure for the Push-Pull LED drivers and PIN diode readout boards used by the TELLIE system. Similar procedures were originally run at Sussex before shipping TELLIE to SNOlab. The following script borrows heavily from the full procedure set described in SNO+-doc-3148-v1. A number of reductions and revisions have since been made, in particular updates to the software and data taking / processing procedures. These modifications were made to provide more accurate measurements of the channel-by-channel emission profile of the system in preparation for re-running the calibration underground at SNOlab.

TELLIE driver testing

Overview

The driver characterisation setup is shown in Figure 2. This setup runs the drivers as they will be at site, using a monitoring PMT and oscilloscope to characterise the time profile and amplitude of their LED pulses. The measured amplitude can then be compared with the internal PIN diode's response. The driver box (a) is connected via a 45 m PMMA optical fibre (c) the PMT (d). The PMT power supply (e) is monitored by the multimeter (f). The oscilloscope (h) is used to measure the rise time, fall time, width and the amplitude of the PMT pulse. The control box (i) for the drivers is powered by the same supply as the driver box (j). The second oscilloscope (k) is used to set up the PIN's amplifier, shown in detail in Figure 4(b). The temperature within the driver box is measured with the temperature monitor (b), the air-conditioning thermostat (g) is used to keep the lab temperature constant. Although not pictured, in the case of slave mode calibrations a signal generator (TLL/ECL) will also be required, connected to the trigger_in port on TELLIE's control box.

In re-running the measurements at SNOlab (b) and (g) will not be directly available. However, SNOlab is temperature controlled to 20°C and 46% humidity [1]. Additionally, only one oscilloscope is available underground at SNOlab ((h) was shipped with the rest of the system). This is not a problem as a maximum of four channels are required to complete these procedures: One for the trigger out signal from TELLIE's control box, one for the PMT response signal and two for probes used to set-up the PIN diodes response.

In their final operational configuration the driver boxes will be mounted in a rack on deck, each connected via 2 m of optical fibre to the patch panel. The patch panel then connects via 45 m fibres to the PSUP nodes. Hence, for these tests the drivers will be connected to the monitoring PMT in a similar arrangement using a 2 m + a 45 m fibre.

The stack of driver boxes are operated through the *control box*. The control box contains a PIC-18F452 Peripheral Interface Controller (PIC) chip, pre-loaded with a set of C functions which can be called to control the system. During SNO+ data running functions will be called by the DAQ system (ORCA), but during these tests the control box will be interfaced with a set of python scripts running off a the TELLIE DAQ laptop. The laptop plugs directly into the control box via USB. The python scripts themselves can be found at [2].

Each of the twelve *driver box's* contains eight driver channels ($8 \times 12 = 96$ channels in total). A single driver channel is defined by a Push-Pull driver and it's associated LED and a PIN diode to monitor the light response, which are held within a brass *cone*. The light is coupled out of the cone by a 0.45 m length of PMMA optical fibre. These fibres are drilled into the LED's plastic casing one end, terminating at the box output with Thorlabs ST connectors.

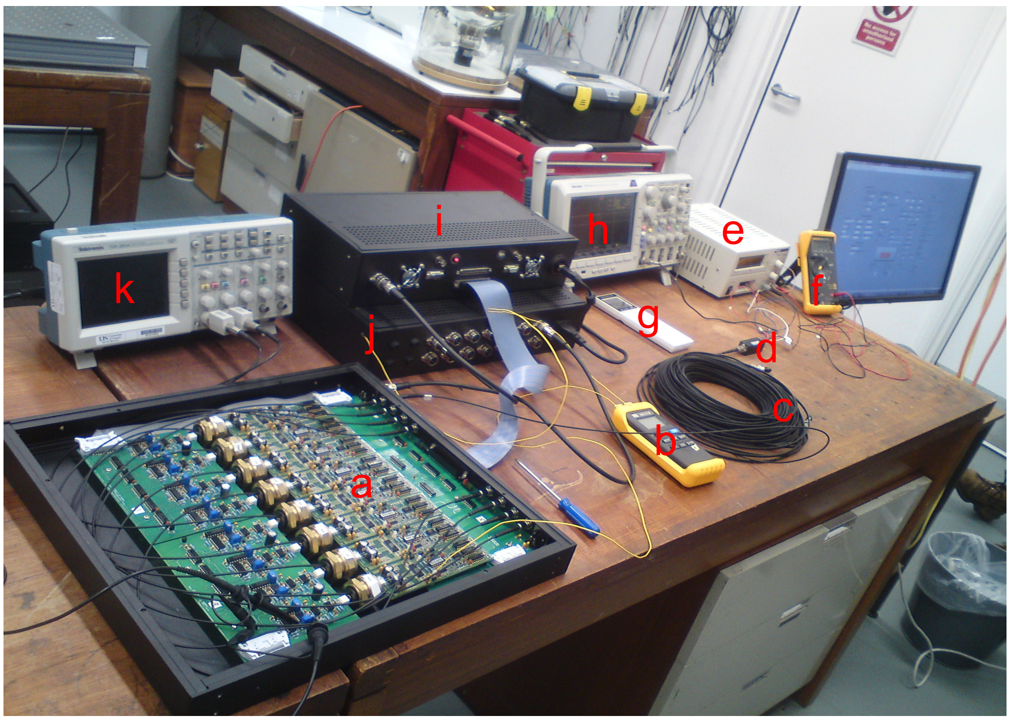


Figure 2: *PIN and driver characterisation setup. Driver box (a), Temperature monitor (b), Optical fibre (c), PMT (d), PMT power supply (e), Multimeter (f), Air-conditioning thermostat (g), Oscilloscope (h), Control box (i), Power supply for driver and control boxes (j), Oscilloscope (k).*

Each of the Push-Pull driver boards are mounted on a motherboard which is connected via a ribbon cable to the control box. A description of the current channel-by-channel hardware status of tellie can be found [3]. This information is also included (with additional run range indexing) in the channel-by-channel calibration documents uploaded to the tellie couchdb after each calibration campaign.

The Push-Pull drivers were designed with three current variables which could be used to manipulate the driver's pulse shape: IBI, IOP and IPW. IBI sets the maximum length of time that a current can be driven to the LED, IBI is fixed on this version of the drivers. IOP sets the amplitude of the current pulse through the LED. IPW sets the width of the current pulse and is used as a direct control of the intensity. As IPW approaches IBI the pulse goes to zero. It had been shown in tests carried out by Dr. Matt Mottram and James Waterfield that the IPW has the greatest effect on the photon intensity. In order to minimise uncertainties added by correlations between the IOP and IPW parameters, the IOP is held constant and only IPW is varied for these characterisations. Further, detailed discussion of the drivers can be found here [4].

Connections and experimental arrangement

TELLIE hardware

During a calibration run all thirteen TELLIE LED driver boxes should be connected to the power box via multi core cables with 8-pole Din connectors. The original calibration run at Sussex only connected a single box during calibration. It was later discovered that the extra passive load associated with having all boxes connected would overwhelm the +5V line. Hence, for all of these measurements, where-ever possible, TELLIE should be operated exactly as we plan to use it under normal operating conditions. All photon calibrations should, therefore, ideally be run with TELLIE fully racked in it's intended position at the back of the DCR.

Each driver box is connected to the control box via a linked ribbon cable, daisy-chained between the boxes. The control box has ports for two ribbon cables each of which can connect seven driver boxes. As a result, a total of fourteen driver boxes can be connected to one control box. It only necessary to have the ribbon cable connected to the driver box being tested, but, as described above, it is preferable to have all driver boxes racked and fully connected when performing calibrations.

On the motherboard of the driver box there is a Board-Select jumper next to the control box connection. This jumper identifies the driver box to the control box as box 1 to 7. The control box then addresses those box's on the lower ribbon cable with a zero offset and

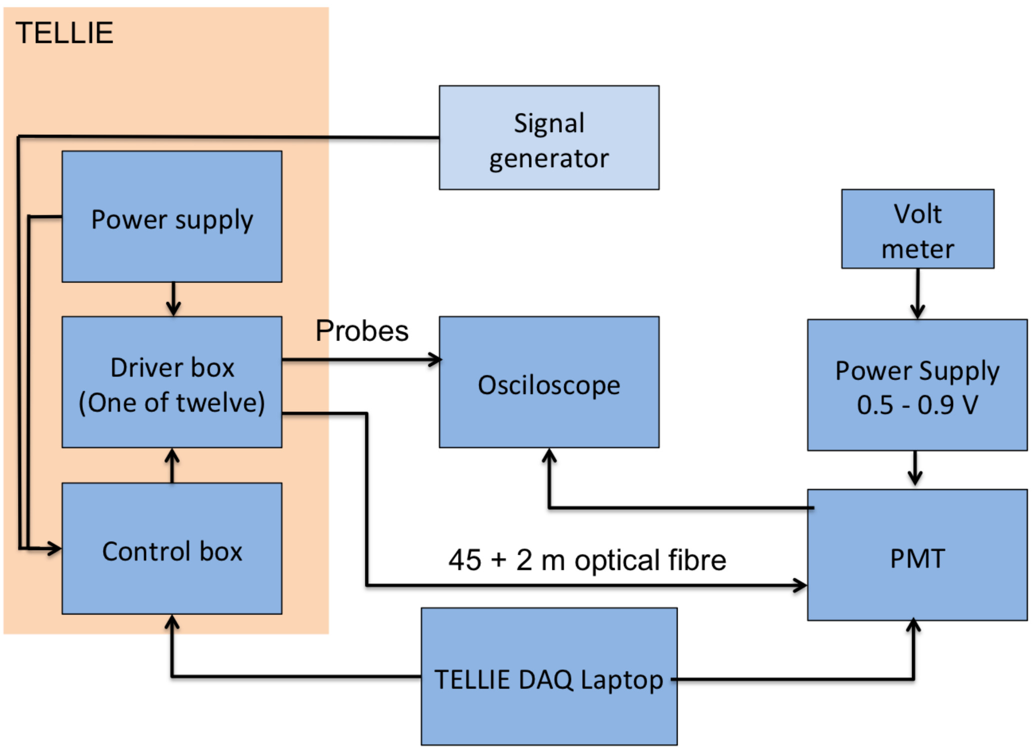


Figure 3: *Basic setup of PIN and driver characterisation.*

those on the upper ribbon with a numerical offset of +7. Therefore, a box with the jumper positioned to 1 on the lower set is identified as $0 + 1 =$ box 1, and the box with jumper positioned to 1 on the upper set is identified as $1 + 7 =$ box 8. Driver box 1 contains channels 1 to 8, box 2 channels 9 to 16 and so on, until channel 112 in box 14. To address a specific channel only its number, calculated in this way, is needed.

When operating in slave mode TELLIE requires a input trigger signal in order to fire. This signal can be either TTL or ECL type and is received by the TELLIE control box which has individual, labelled trigger_in ports for both types. If slave mode operation is requested and a trigger signal is not supplied TELLIE *will not fire*.

The 'TELLIE DAQ' MacPro used to run the python scripts [2] connects to the control box via a standard A-B USB. The TELLIE DAQ MacPro is stored underground at all times so will be available for the re-calibrations at SNOLab. A back-up is also available underground in case of any major failures.

Optical readout chain

With all the TELLIE electronics hardware now described, we move onto the optical readout chain. Before any fibre connections are made, each end is to be cleaned with the Thorlabs fibre connector cleaner. The 'fitted connections' at the output of each driver box should ideally be sprayed with pressurised air to remove any dust. However, for cleanliness reasons, pressurised air is only available underground in the carwash so this step will have to be skipped.

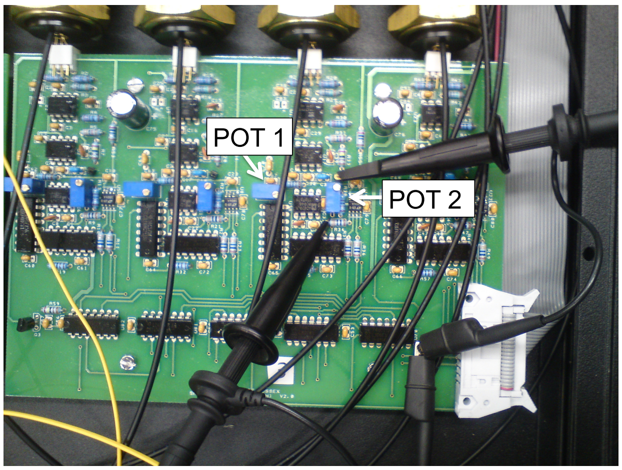
The PMT used here is a Hamamatsu H10721-210, with the control voltage set to **0.5 V** or **0.7 V** depending on pulse intensity. The PMTs gain was calculated underground at SNOlab in July 2015, the results of which are given in Figure 5(b). A value of the control voltage is recorded in the file name of each dataset.

The QE can be calculated from the cathode radiant sensitivity,shown in Figure 5(a), which is $77.4\,\mathrm{mA\,W^{-1}}$ at 501 nm, as follows:

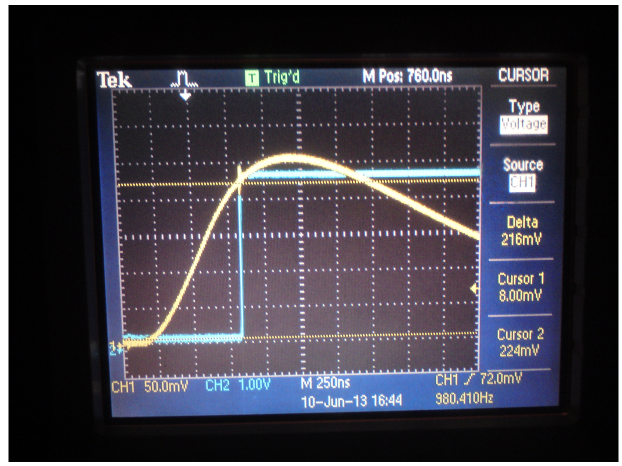
$$\frac{77.4 \times 10^{-3}\,\mathrm{CJ^{-1}}}{1.6 \times 10^{-19}\,\mathrm{C}} = 4.84 \times 10^{17}\,\mathrm{eJ^{-1}}$$

$$\frac{1}{E_\gamma} = \frac{\lambda}{hc} = 2.52 \times 10^{18}\,\gamma\mathrm{J^{-1}}$$

$$\frac{4.84 \times 10^{17}}{2.52 \times 10^{18}} = 19.2\%$$



(a) *Probe connection points for PIN diode.*



(b) *Scope displaying PIN pulse (CH1) and sample point (CH2), the gain determines the aptitude of the pulse.*

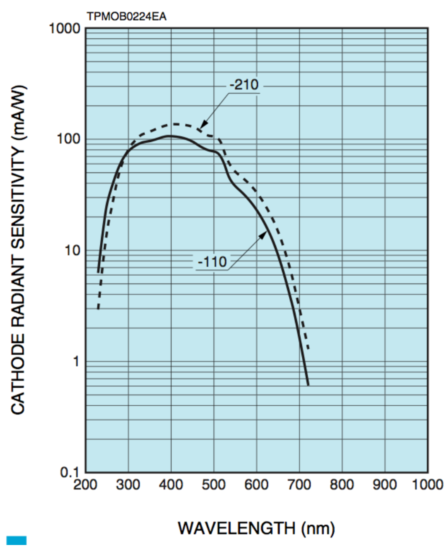
Figure 4: PIN diode probes and pulse shape

Setting the PIN diodes

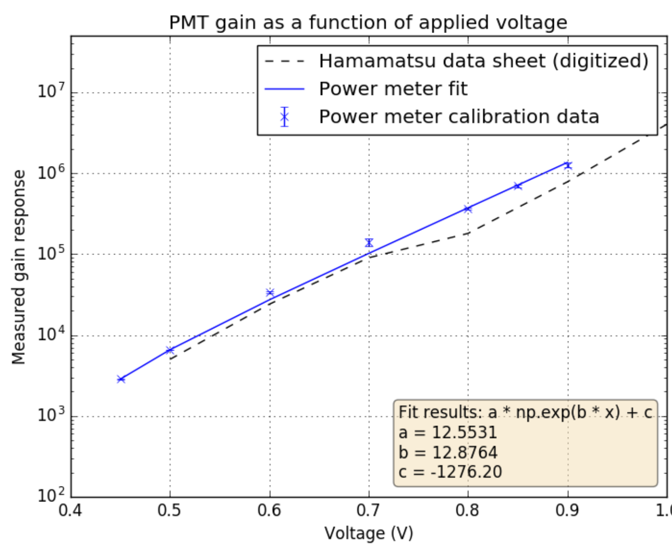
The main purpose of these procedures is to re-tune the gain of the PIN diode to me more sensitive to the lower 20% of TELLIE's operational range (light output). This is the range at which TELLIE will be operated for the PCA calibrations and so is the most important to monitor accurately. If PIN readings are shown to be extremely well correlated with the SNO+ PMT array response then it is hoped PIN readings could be used in a feed-back loop internally within the TELLIE fire sequences, improving stability.

The two scope probes should be set as in Figure 4(a). There is a ground pin in the bottom right hand corner of the picture that the two crocodile clips are attached to. The two probes should then be connected to the 330 Ω resistor and the probe point, as also shown in Figure 4(a). We must then identify the two potentiometers associated with this channel. If we again look at Figure 4(a) the potentiometers are the blue rectangular components. Each channel has one potentiometer to control the position at which the PIN diodes response is sampled by the ADC (POT 1), and one to control the gain of the amplifier associated with the PIN diode's electronic response (POT 2).

To set the two POTS first run the pulse_continuous.py script available at [2]. This requires passing two flagged arguments: -b (the box number) and -c (the channel number within that box: 1-8). Optionally, the user can also pass a -w flag to additionally set the IPW value. This is set to 0 by default and should be run at 0 in the first instance. With the probes attached



(a) *Cathode radiant sensitivity, from which quantum efficiency can be derived.*



(b) *PMT gain as a function of control voltage. A the digitized data sheet values provided by Hamamatsu are also plotted for comparison.*

Figure 5: PMT calibration plots taken from [5].

and the script running, the user should adjust the scope settings to give something similar to Figure 4(b). You're now ready to set-up a channel! To do so, the amplifier's gain (POT 2) should be increased until the response pulse (CH1 in Figure 4(b)) is seen to just saturate. In saturation the peak will flatten off as the amplifier can no longer supply an output voltage proportional to the input. The sample point (POT 1), should then be adjusted until the rising edge of the square pulse intersects the PIN response transient at 75% of it's peak (saturation) value.

That's it! Easy as that.

Channel response checks

Broad sweep

In order to calibrate the response of each LED driver & PIN diode readout channel, we need to acquire some data. As we are calibrating both the energy and timing response of each channel so we need two observables: The (TTL) trigger_out from the control box and the PMT's response signal, which should be connected via 50 Ω BNCs to Channels 1 and 2 of the oscilloscope respectively.

To run this test, first we must ensure the optical readout chain is properly set-up. The light from the TELLIE channel of interest should be coupled into the testbench PMT via a chain of two PMMA optical fibres. Firstly a 2 m fibre to emulate the TELLIE -> patch panel connection, then a 45 m fibre to emulate the patch panel -> PSUP fibre. The end of the combined 47 m fibre chain should be coupled into the testbench PMT. Remember **the PMT must not be subjected to ambient light while biased**. It is extremely important the PMT is not biased when coupling / un-coupling fibres from the PMT. At best this will ruin the gain calibration, at worst it will completely destroy the PMT.

Once connections have been properly made bias the PMT and use the POT on the PMT control box to set the gain to 0.5 V.

To run the data acquisition simply run the ipw_broad_sweep.py script. This script requires two flagged arguments: -b (the box number) and -c (the channel number within that box: 1-8). It will step over the channel's full operational range, acquiring data at each step in a little under 10 mins.

The recorded data is stored by box number under the ./broad_sweep master directory. All data associated with box 1 is therefore stored in ./broad_sweep/Box_1/. Within the box-wise directories .txt files containing the results of measurements made during data taking are stored. The raw data (i.e. the waveforms saved directly from the scope) can be found under

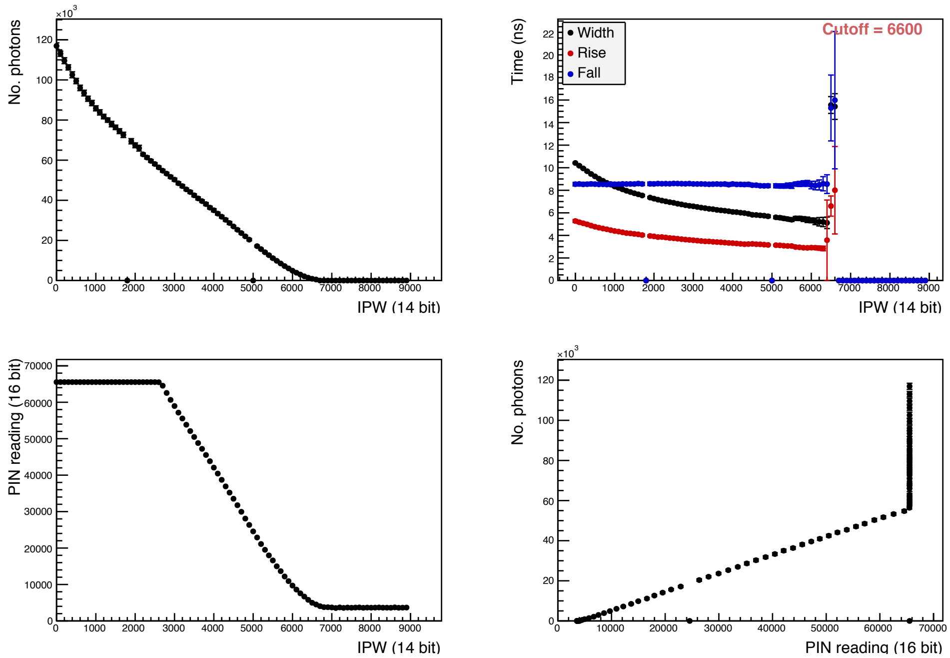


Figure 6: *Master plot as returned from running plot_ipw.py on a broad sweep data set.*

./broad_sweep/Box_1/raw_data/.

To generate plots from the recorded data sets, use plot_ipw.py. This script requires one flagged argument: -f (the path to the .txt file of results generated by ipw_broad_sweep.py), and will generate a master plot as shown in Figure 6, along with a number of additional plots for interest. The master and additional plots are stored at ./broad_sweep/plots/ and ./broad_sweep/plots/channel_XX/ respectively.

Low intensity sweep

During SNO+ data running TELLIE's main purpose will be to provide single photoelectron events at the PMT array for PMT calibrations (PCA). In order to fulfil this requirement, it has been shown in simulation studies by Freija [6] that TELLIE must operate in the regime of <10,000 photons/event emitted from the end of the 45 + 2 m fibre chain.

To better characterise this operational range a low intensity sweep must be run by setting the PMT gain to 0.7 V and running the ipw_low_sweep.py script. This script requires two flagged arguments: -b (the box number), -c (the channel number within that box: 1-8). The script looks up the most recent broad_sweep data file for the requested channel and steps up

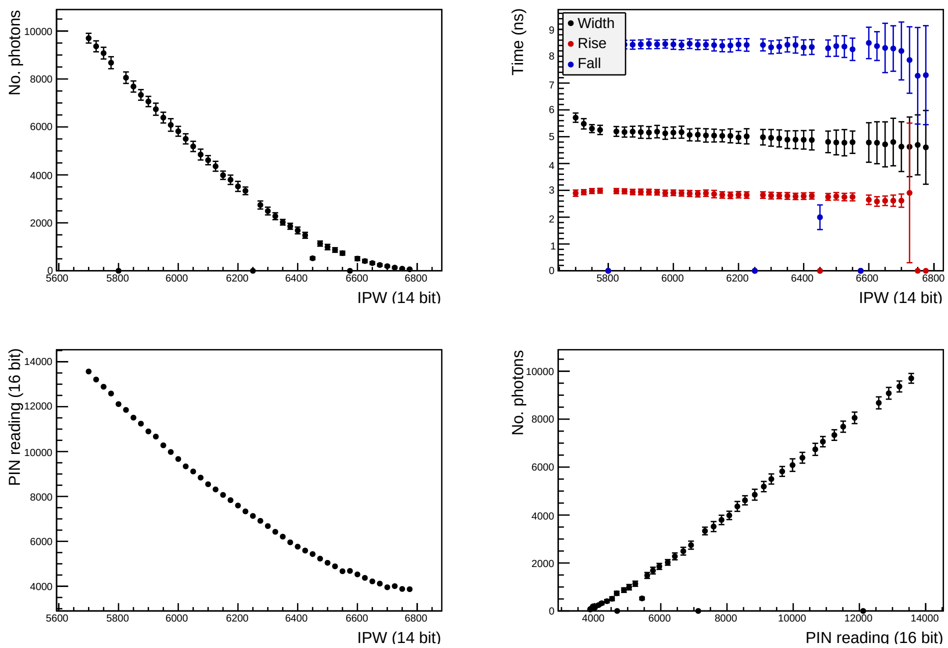


Figure 7: *Master plot as returned from running plot_ipw.py on a low intensity data set.*

in IPW from the last data point with > 100,000 photon/pulse.

To generate plots of the low intensity data set, use plot_ipw.py as described above. The resulting masterplot will resemble that shown in Figure 7.

Quick reference

At the start of each day the user will have to navigate to the TELLIE_calibration_code directory and run: **source env.sh**. This will set-up the library paths etc so python knows where to look for all our functions.

PIN set up:

- Connect probes and set-up oscilloscope to monitor as in Figure 4.
- Run pulse_continuous.py script: **python pulse_continuous.py -b** [**box number**] **-c** [**channel number within box: 1-8**]
- Adjust the amplifiers gain (POT 2) until the PIN response pulse can be seen to just saturate.
- Adjust the sample point (POT 1) to approximately 75% of it's peak (saturation) value.

Broad sweep:

- Make sure the **PMT is turned off**. If it breaks we've got serious issues.
- Uncap the PMT and couple in light from TELLIE channel of interest via a 2m patch fibre.
- Connect output of PMT to Channel 1 of oscilloscope.
- Turn on PMT bias and set gain to **0.5 V**.
- If operating in slave mode **check the frequency of the trigger_source**
- Run ipw_broad_sweep.py script: **python32 ipw_broad_sweep.py -b** [**box number**] **-c** [**channel number within box: 1-8**]
- Run plot_ipw.py script: **python plot_ipw.py -f** [**path to file**]

Low intensity sweep:

- Set PMT gain to **0.7 V**.
- If operating in slave mode **check the frequency of the trigger_source**
- Run ipw_low_sweep.py script: **python32 ipw_low_sweep.py -b** [**box number**] **-c** [**channel number within box: 1-8**] **-x** [**cut-off ipw**]
- Run plot_ipw.py script: **python plot_ipw.py -f** [**path to file**]
- **Turn off bias to PMT**.

Quality checks

There are a number of key quality checks which should be considered before moving onto the next channel:

- The PIN diode does not saturate below 40,000 photons. This is checked using the bottom left plot shown in Figure 6. If the PIN *DOES* saturate below 40,000, the gain has been set too high. The operator will have to re-run the set-up ensuring a lower gain setting for the PIN diodes amplifier (i.e. re-adjusting POT 2).
- There should be no more than 4-5 missed data points in the low_intensity sweep. You can see in Figure 7 a few data points in the mid-range are set at zero. This is an artefact of an internal glitch in the scope's data acquisition - sometimes it doesn't properly recognise triggers. The scope underground at SNOlab is a more advanced model and I haven't seen this effect with that scope so fingers crossed it won't be a factor - but must be considered all the same!
- Expect this list to be added while we're doing the first runs at site. All seems well on the couple of example channels we have here at Sussex, but I fully expect additional artifacts to show up once we really get going on the full 96 channels at site.

Figure 8: *...well done, you look tired, and a lot like James... Go home and rest.*

Bibliography

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