Characterisation Procedure for TELLIE PIN diodes

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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 used by the TELLIE system. These 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, specifically for re-running the calibration on site 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 the 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. In re-running the measurements at SNOlab only one oscilloscope will be available. This is not a problem as only three channels are required - two for the probes and one for the pmt.

At site 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 (currently 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 [1].

Each of the twelve *driver box's* contains eight driver channels ($8\times12 = 96$ 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. Each of the Push-Pull driver boars are mounted on a motherboard which is connected via a ribbon cable to the control box.

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 potential difference can be applied across the LED, IBI is fixed on this version

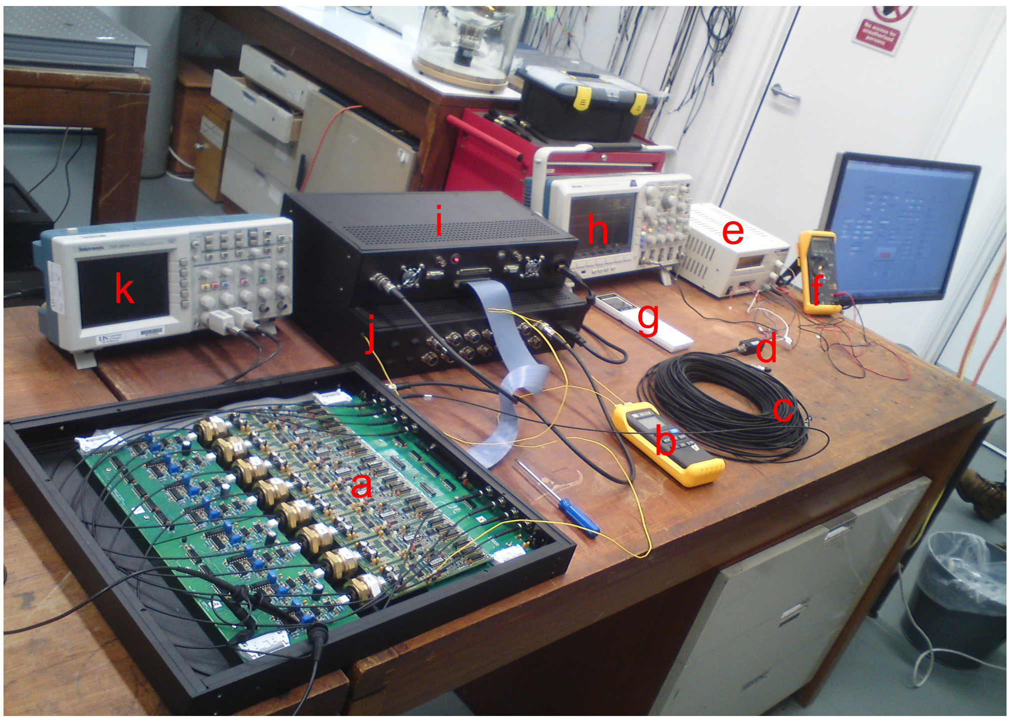


Figure 2: *PIN and driver characterisation setup. Driver box (a), Temperature monitor (b), Optical fibre (c), PMT (d), PMT power supply (e), Multimeter (f), Air-conditioning thermostat (g), Oscilloscope (h), Control box (i), Power supply for driver and control boxes (j), Oscilloscope (k).*

of the drivers. IOP sets the size of the potential difference across the LED. IPW sets the time that the potential difference is applied for, controlling the width, and to an extent 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 [2].

Connections

For all measurements the lab temperature is maintained at approximately 21° C using the air-conditioning, with the thermostat mentioned above. For the re-calibration to be done at SNOlab, the procedures are to be carried out on the deck (or in the control room) where the temperature is constantly controlled.

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 also be sprayed with pressurised air to remove any dust.

The 'TELLIE DAQ' MacPro used to run the python scripts [1] 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.

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 robin 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.

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 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.

Each PIN diode has two potentiometers, shown in Figure 4(a), that allow the PIN's gain and sample point to be set. Probes can be connected to the $330\,\Omega$ resistor and the probe point also shown in Figure4(a). The gain is set to allow maximal sensitivity to the low light levels

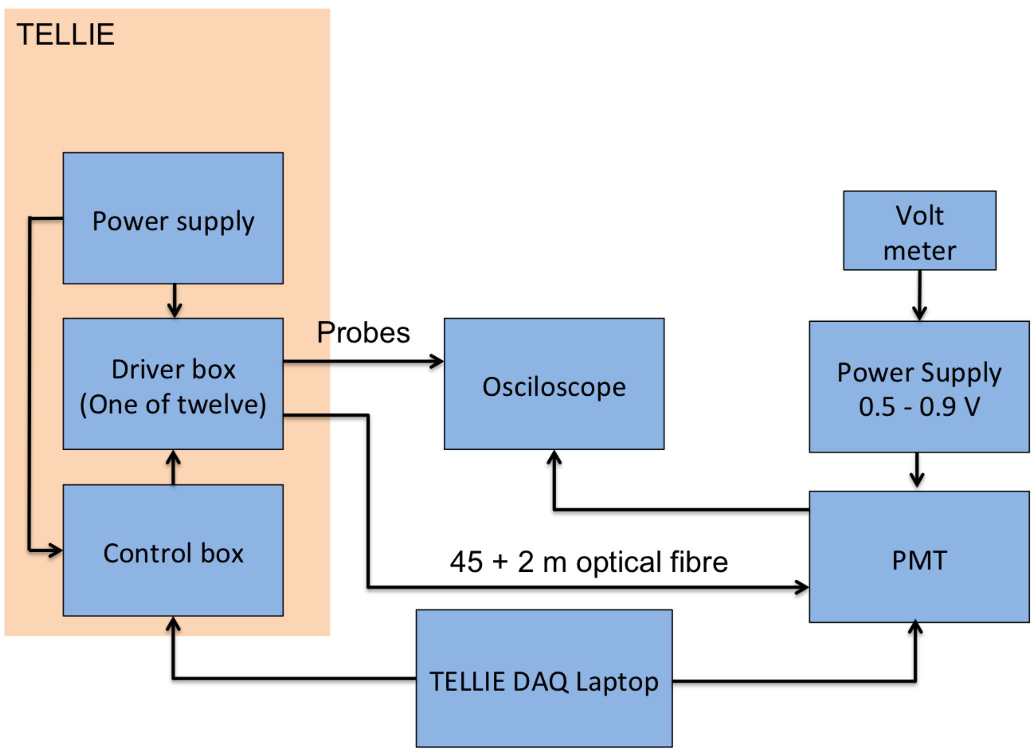
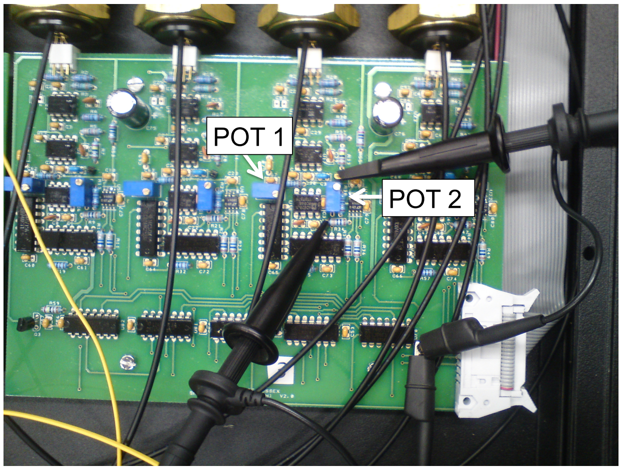
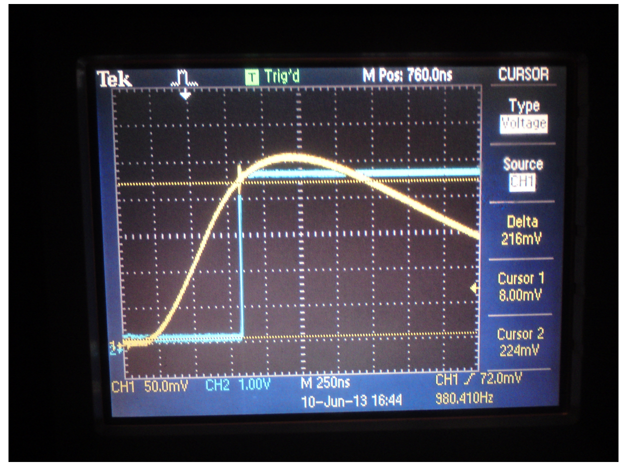


Figure 3: *Basic setup of PIN and driver characterisation.*



(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

without becoming unstable.

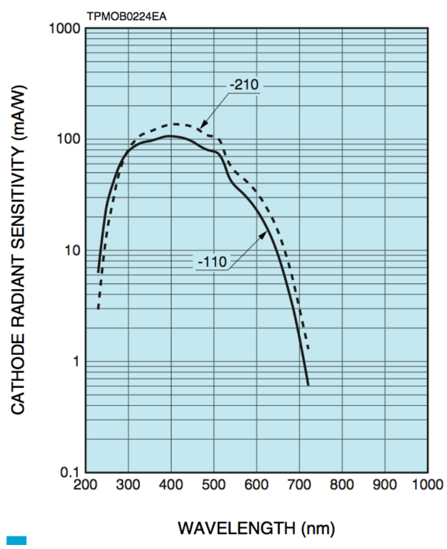
The PMT used here is a Hamamatsu H10721-210, with the control voltage set to **0.6 V** or **0.8 V** depending on pulse intensity. The PMTs gain was calculated at Sussex on the 22/05/2015, the results of which are given in Figure 5(b). A value of the control voltage is recorded in the file name of each 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:

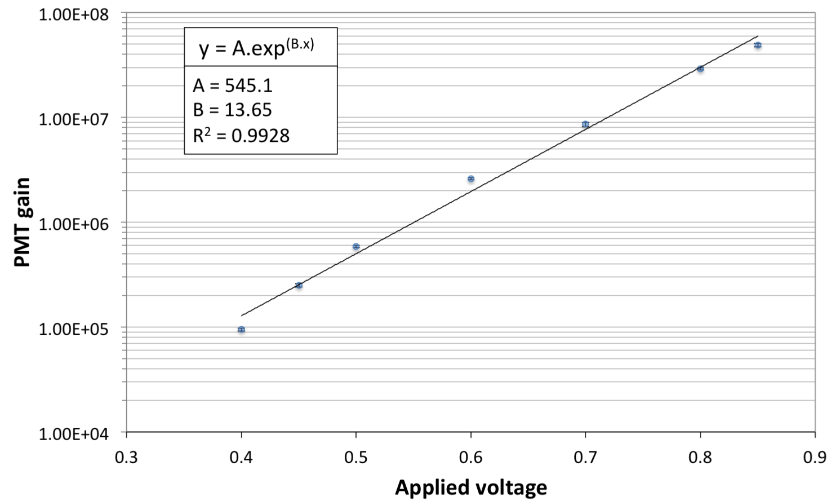
$$\frac{77.4 \times 10^{-3}\,\mathrm{CJ^{-1}}}{1.6 \times 10^{-19}\,\mathrm{C}} = 4.84 \times 10^{17}\,\mathrm{eJ^{-1}}$$

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

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



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



(b) *PMT gain as a function of control voltage.*

Figure 5: PMT calibration plots taken from [3].

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 [1]. 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 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

To check the response of the channel you've just set-up, we're going to need to take some data. As, in the first instance, it's most important to see how the channel responds over a full range of IPW settings, we want to use the ipw_broad_sweep.py script. This script, much like pulse_continuous.py, requires two flagged arguments: -b (the box number) and -c (the channel number within that box: 1-8). Insure the PMT is connected to channel 1 of the scope with it's gain set to 0.5 V. The script will take care of the rest for you, saving the data under the local directory, ./broad_sweep. **NOTE: This script uses the NIVISA library, which is only available in 32 bit. The user must therefore use python32 in place of the normal python call**. It will take 20 mins to take a full data set. Go have a cup of tea.

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 ./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.

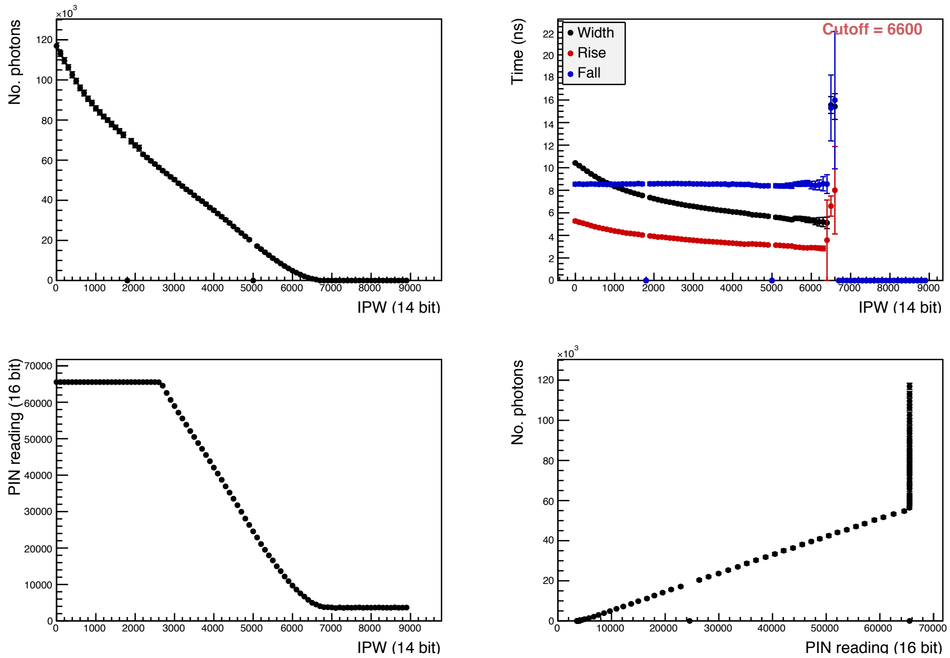


Figure 6: *Master plot as returned from running plot_ipw.py on a broad sweep data set.*

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 [4] that TELLIE must operate in the regime of <10,000 photons/event exiting the end of the 45 + 2 m fibre.

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 three flagged arguments: -b (the box number), -c (the channel number within that box: 1-8) and -x (the cutoff ipw value as seen in the results of the broad sweep). The cutoff ipw is the value at which the light intensity was no longer visible (or could not be accurately measured) by the pmt during a broad sweep. The cutoff ipw is given on the master plot for that specific channel, stored at ./low_intensity/plots/. **NOTE: As in broad sweep, this script uses the NIVISA library, which is only available in 32 bit. The user must therefore use python32 in place of the normal python call**

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.

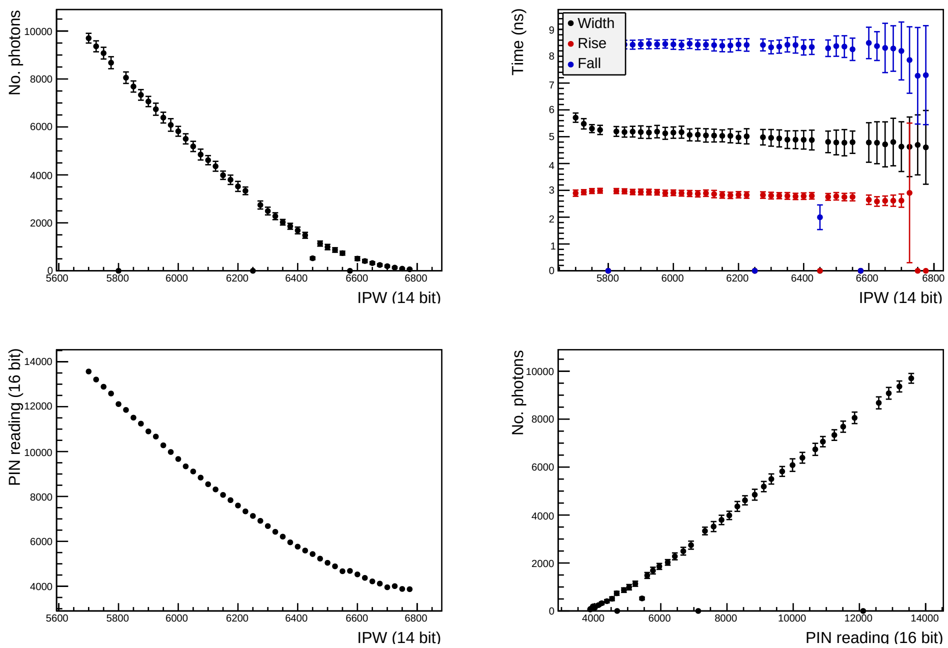


Figure 7: *Master plot as returned from running plot_ipw.py on a low intensity data set.*

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.

Broad sweep:

- Connect PMT to Channel 1 of oscilloscope.
- Set PMT gain to **0.5 V**.
- 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:

- Connect PMT to Channel 1 of oscilloscope.

- Set PMT gain to **0.7 V**.
- 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]**

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.

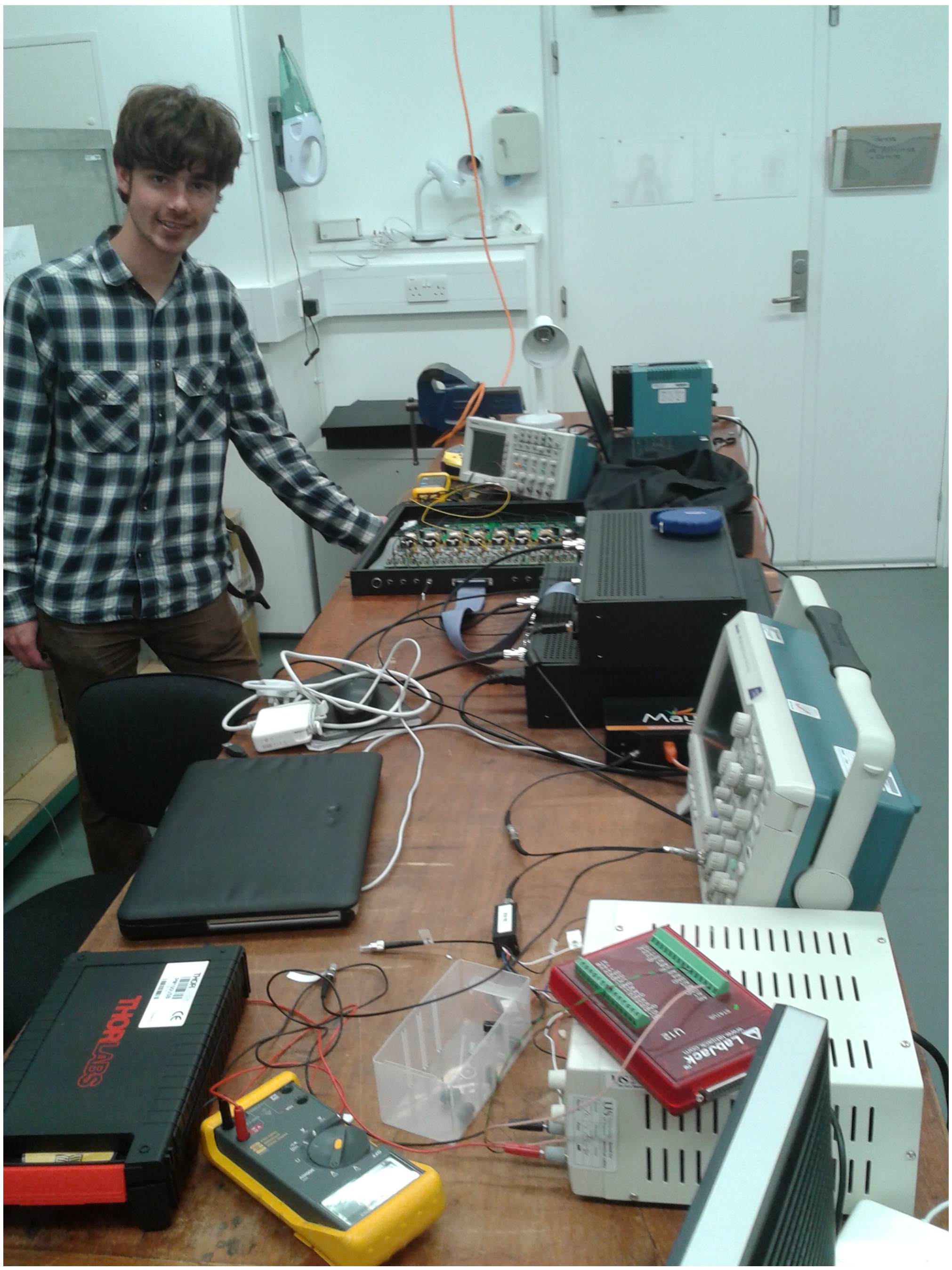


Figure 8: *...well done, you look tired, and a lot like James... Go home and rest.*

Bibliography

[1] Leming. `https://github.com/Sussex-Invisibles/TELLIE_calibration_code`.

[2] R. Alves, S. Andringa, S. Bradbury, J. Carvalho, D. Chauhan, K. Clark, I. Coulter, F. Descamps, E. Falk, L. Gurriana, and et al. The calibration system for the photomultiplier array of the sno+ experiment. *Journal of Instrumentation*, 10(03):P03002P03002, Mar 2015.

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[4] F. Descamps. Tellie hit probabilites. `https://www.snolab.ca/snoplus/private/DocDB/0017/001703/003/TellieHitProb-11Feb2015-v2.pdf`.

[5] G. Lefeuvre. Ellie control integration. *SNO+ DocDB*, (1682), 2012.