JSNS^2 nanopulser optical calibration system

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ABSTRACT

This note describes the the JSNS^2 nanopulser optical calibration system. The document discusses the requirements, design, testing, as well as the control software and the operation. This is a live document and should be updated as the system expands.

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Introduction

The JSNS^2 experiment[1] is a relatively small liquid scintillator detector. It relies on precise timing in order to seperate the scintillation light from Cherenkov light, which is crucial for background and signal separation. This note describes the JSNS^2 nanopulser optical calibration system that will be used to do the timing calibration, as well as the gain calibration.

We start with a description of the requirements as set by the JSNS^2 collaboration. Next is a description of the system in the experiment. We then describe the control software, followed by a section on the analysis strategy.

This document is maintained by the corresponding author and can be downloaded or cloned from github[2]. If you have any updates, please contact him (details above).

Requirements

The calibration system has the following requirements:

1. The system is controllable via simple to use, and flexible software.

2. The part of the system that is inside the LAB filled volume is compatible with LAB.

3. The system does not cause interference on the PMT array.

4. Each pulser produces a very small width in time optical pulse (less than 1 ns risetime at low intensities and less than 2 ns falltime).

5. The system provides full optical coverage of the PMT array for both 420 nm and 355 nm.

6. The system provides a trigger pulse that can be delayed, with negative amplitude and less than 1 1 V, to be read-out with one channel of the VX1721 flash ADC read-out system.

System design

In this section, we discuss the overall layout of the system, the electronic and mechanical design and the software.

Overall design

The design is based on the initial proposal by Matsubara-san, with some modifications to ease installation and improve the coverage of the light on the PMT array.

Figure 6 shows the overall layout of the system. The LEDs are mounted on next to the PMTs, on the boards holding them. The system consists of six 'branches': a cable string with a data and power line that at certain intervals holds a 'pulserhead': an electronics board with digital logic and an ultra-fast LED pulser. Each string has either two or three pulserheads. In total, there are twelve pulserheads with a 420 nm LED and two pulserheads with a 355 nm LED (the 355 nm light will be absorbed almost immediately and emitted randomly in all directions as a longer wavelength). Each branch is terminated with a connector containing a 120 Ω resistor on the data line.

The cable exit the experiment through four flanges. The cables, made out of (expensive) teflon coated cables are then connected to a junction box, where they connected to (cheap) 15 m long ethernet cables. These cables are connected to the nanopulser control box, located in the DAQ racks. The controller box talks to the DAQ via the network (ssh to the raspberry pi inside the controller box). The junction box is grounded and a ground cable connects to the controller box as well. The controller box also provides a trigger signal in-sync with the optical pulse. There are programmable delays that control the timing between the optical pulse and the trigger pulse for each of the pulserheads.

Table 1 shows the overall configuration of the branches, as well as the branch and the pulserhead IDs.

Table 1. Configuration of the JSNS^2 nanopulser optical calibration system, up to the junction box.

Branch	Flange	Cable length (m)	Pulserhead ID	λ_{LED} (nm)	Cable length (m)	Pulserhead ID	λ_{LED} (nm)	Cable length (m)	Pulserhead ID	λ_{LED} (nm)
1	2	5.5	1	420	2.2	2	355	2.2	3	420
2	2	4.5	4	420	3.0	5	420			
3	2	9.0	6	420	3.0	7	420			
4	2	13.5	8	420	3.0	9	420			
5	2	9.0	10	420	3.0	11	420			
6	2	10	12	420	2.2	13	355	2.2	14	420

System performance

Pulserhead

Note that for transfer the maximum energy in a fast pulse, that we found that it is important that the legs of the LEDs are not shortened, but bend out to fit.

Pulserhead programming

The Pulserheads are each programmed for a specific position on the branch and with its own unique ID (1-14). The programming can be done separately from the system, as shown in Figure 4, with a custom cable providing the 9 V power for the PIC chip[1]. The code is loaded onto the PIC chip via a commercial interface (microchip PICkit3) with a custom cable to the pulserhead. Note that, as shown in Figure 4, the grey lead lines up with the arrow on the PICkit3 interface. On the other side, the green lead is closest to the LED on the pulserhead. The connector on the pulserhead is slanted an slightly bend, to make it fit into the pulserhead's acrylic housing. Therefore, take extra care when connecting to make sure a good contact is make.

The software for the pulserhead programming can be found on github[3]. This contains a zip file (PICkit3.zip), which contains the windows compatible executable file PICkit3.exe, as well as other (required) input files for the program. It also contains the 14 hex files to be loaded onto the pulser: nanoSlaveTrig_X.hex, where X is a letter from A-N. This corresponds to pulser ID 1-14, respectively, as shown in Table(i.e., A is for pulser head 1, etc.).

The program PICkit3.exe is started by double-clicking (make sure the PICkit3 device is connected and recognised, otherwise the next step is not possible). Next, select the PIC chip to program: under menu 'Device family', select **MidRange**. Then, under 'Device', select **PIC16F88** (note there are a lot of models). If the set-up is correct, you can now read the PIC chip by pressing the 'Read' button. This take a little and a green progress bar will appear until the commend read has finished. This should change the hex values shown in Program Memory from their default values to all different values.

If this was successful, load a hex file by clicking 'Import Hex' from the 'File' menu. Next, click 'Write'. Again a green progress bar should appear to show the progress. Wait until the process has been completed. After this, the PIC chip has been programmed and can be disconnected from the power supply and the PICkit3 device.

The perfomance of the pulserheads is documented on github[4], and is summarised in Figure 5.
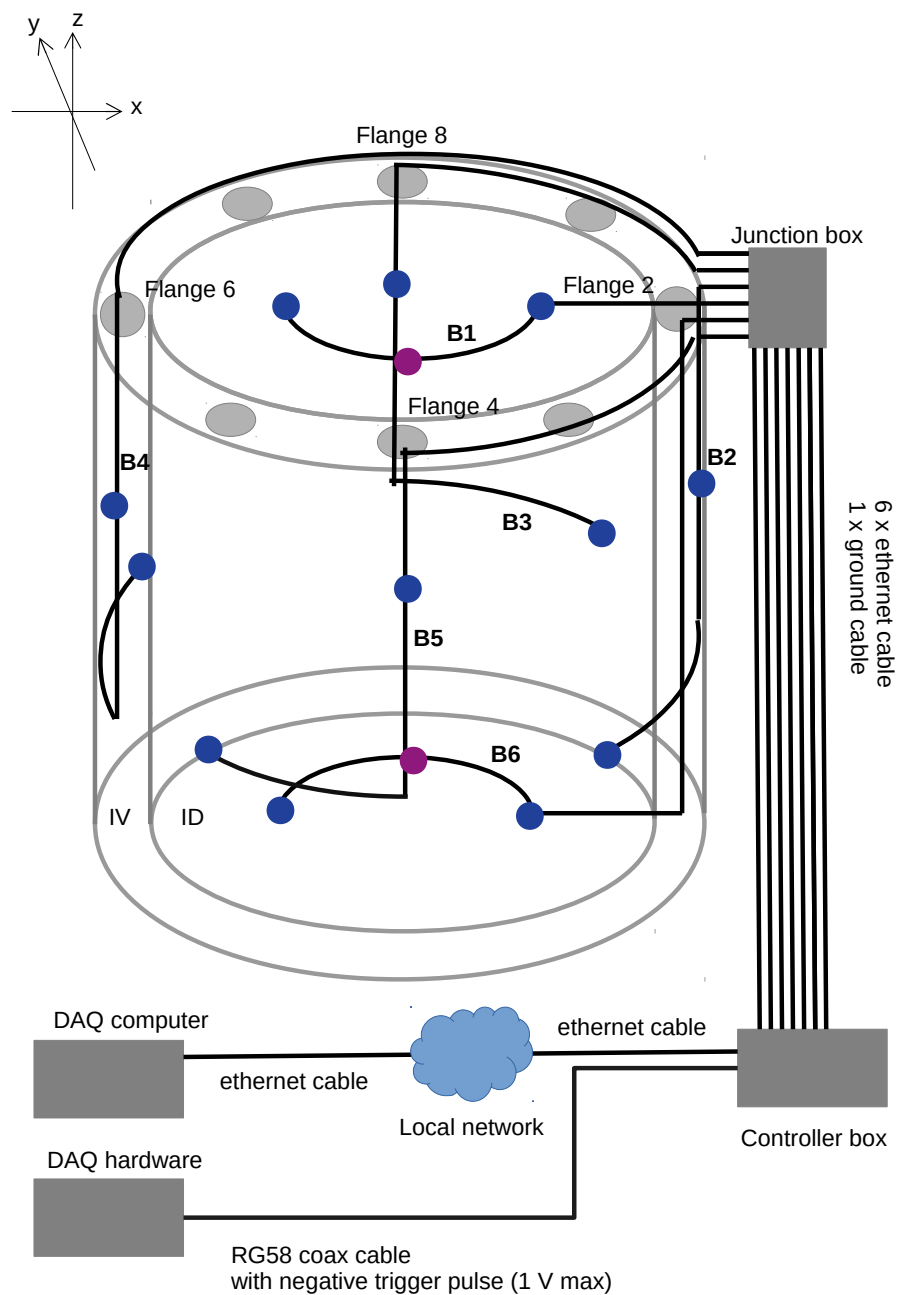
Figure 1. A schematic overview of the nanopulser optical calibration system. The (two) purple points indicate the position of the pulserheads (LED driver boards) with a 355 nm LED, the (twelve) blue points indicate pulserheads with a 420 nm LED. All LEDs point inwards. The numbers B1-B6 indicated the different branches. IV is the Inner Veto volume and ID is the Inner Detector volume.
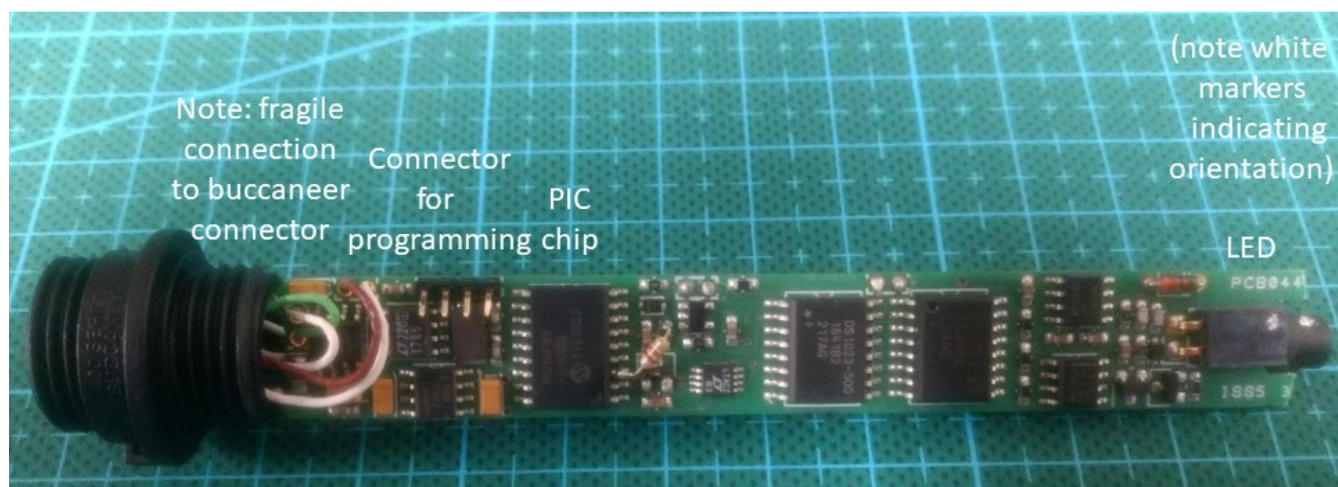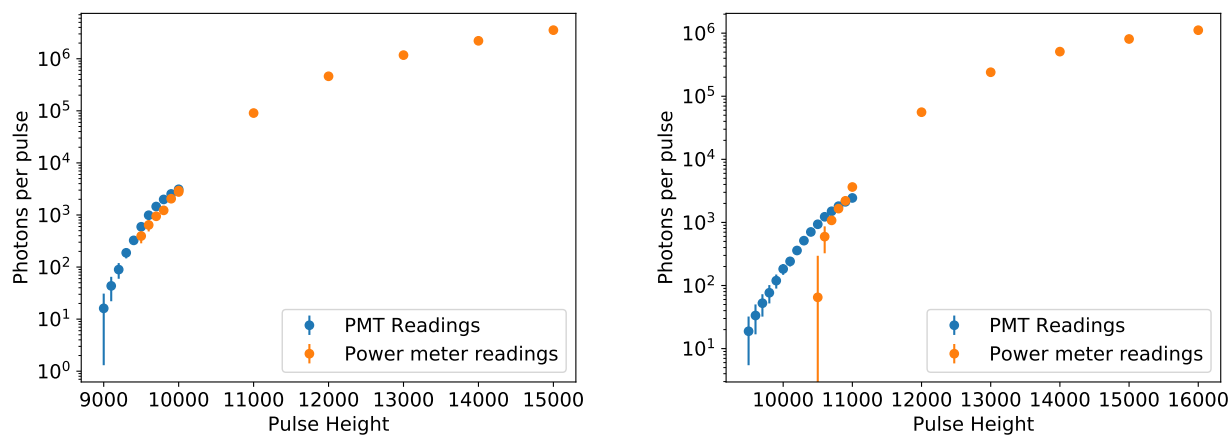
Figure 2. Photo of the a pulserhead, outside of its acrylic housing, with the main components indicated.

Figure 3. Rendered drawing of the acrylic housing, with an O-ring (black in this image, but white in reality).
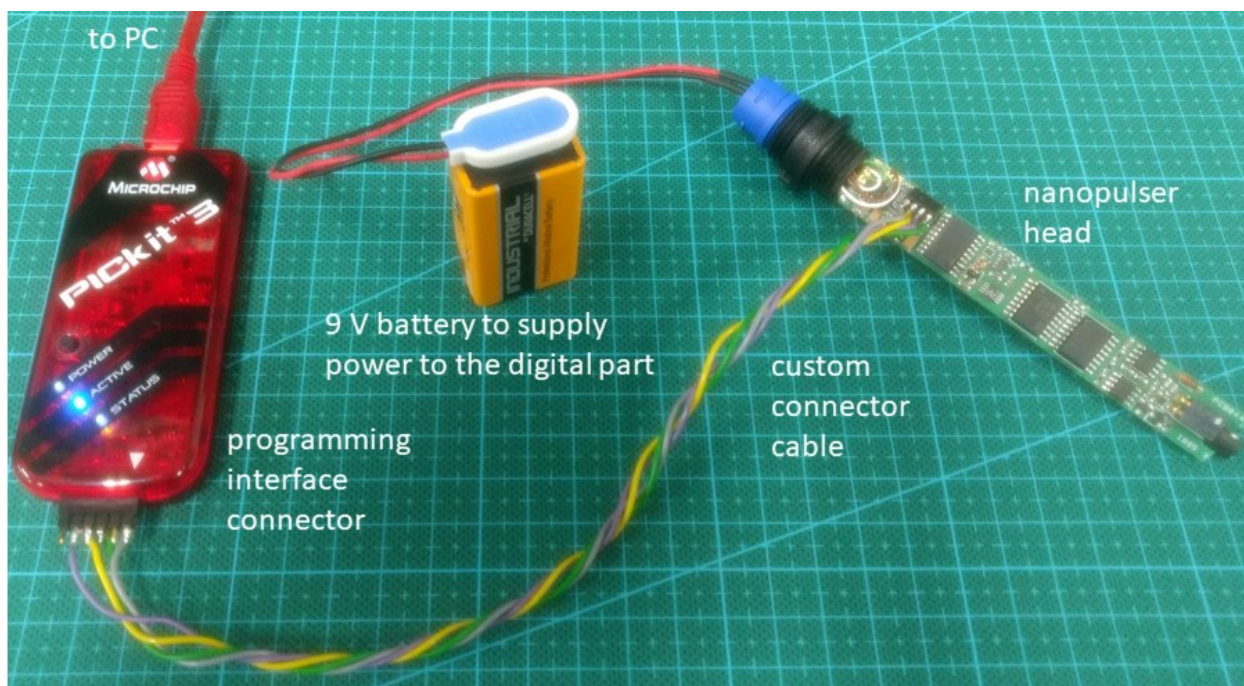
Figure 4. The pulserhead programming set-up (window10 computer needed, not shown here).

Figure 5. The optical output of the pulserheads with 420 nm LEDs (left) and 355 nm LEDs (right). The x-axis is the digital setting used for the measurements. Most of the range is observed with a calibrated optical power meter. At the low end, however, this device was not sensitive enough and a careful extrapolation based on measurement using a PMT is shown. T
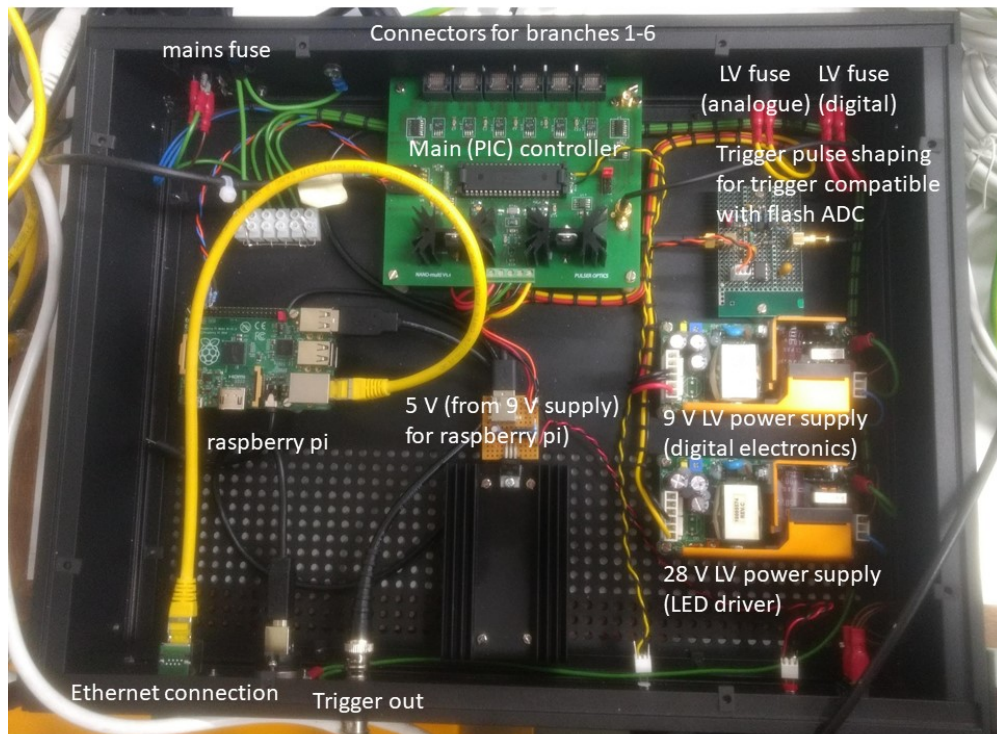
Figure 6. Photo of the control box during commissioning at the University of Sussex, with the main components indicated. Note that all the fuses and connections can be accessed from the outside.

Nanopulser control box

One symptom of a blown fuse can be that the pulser does communicate but either does not produce light, or produces a wide pulse (of the order of 100 ns).

Cable design

The ethernet cables should **never** be unplugged from the box, while the power is on, as the power for both the digital electronics, as well as for the pulser circuits runs through them. Note: accidental hot-swapping can result in one of the fuses blowing. Therefore, always power the system off before connecting or disconnecting the ethernet cables to the control box.

Junction box

At the final installation, the cables should be wrapped with a tie wrap inside the junction box, to avoid damage to the connection by accidentally pull the cables. Note that the (longer) ground cable also needs to be connected to the junction box chassis (see Figure 7).

Trigger delay

When the slave board receives a 'run' command, it outputs a (trigger) pulse, which is sent back to the control board. The time it takes to receive by the control board depends on the cable length. This pulse is internally delayed on the slave board before triggering the LED driver circuit. The delay is preset using two delay lines of step size 5 ns (called 'course trigger delay') and 0.25 ns (called 'fine trigger delay'). By matching the total delay to the cable length, the trigger pulse received at the control box (or beyond) can be made co-incident with the light pulse. The number of programmable steps is 255 for each delay line. Thus the maximum delay is 1,333.75 ns (1270 ns plus 63.75 ns).
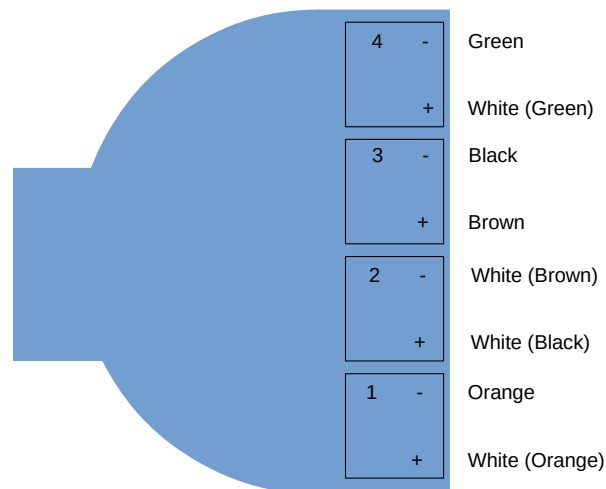
Control software

The software is kept in a github repository[5]. (An older, depricated, version with documentation is also kept in a different github repository[4], for reference only).

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[1]Make sure the battery has enough power left to power the PIC chip.
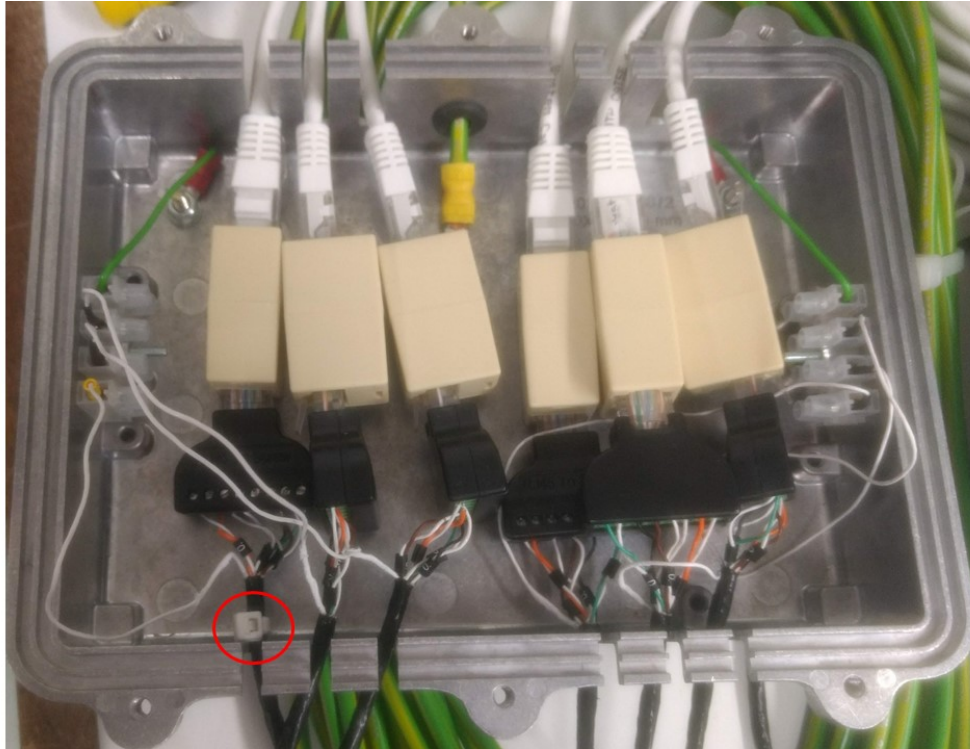
Figure 7. Photo of the junction during commissioning at the University of Sussex. The ethernet cables on the top connect to the back of the control box (this is labeled 1-6 for the branch numbers). The cables coming from the connector need to be wired to the black eight-way connectors in the pictures (details given below). The cables are then connected with the beige mating connectors. After final assembly in the flange, a tie wrap should be wrapped on each cable as a strain relief. This is demonstrated in the bottom left cable (red circle).

Figure 8. A diagram indication how the eight-way connector should be connected to the cables going into the vessel.

A raspberry pi computer, which runs the control software, is situated within the control box. To operate the box you need to ssh into the raspberry pi using `ssh pi@<IP address>`. The MAC address of the raspberry pi ethernet port is `b8:27:eb:ef:45:ee`.

The control software for the driver board are located in the folder: `/home/pi/JSNS2PulserControl/ControlSoftware/`. The script to control the driver boards is: **`test_run.py`**. It takes the following arguments:

`-c` - The pulserhead ID to pulse
`-p` - The pulse height for the driver board, this controls the intensity of each LED pulse. (Ranges from 0 to 16384)
`-d` - The delay between pulses in milliseconds
`-n` - Number of pulses. The number of pulses must be a multiple of 1000, up to 65,025

All arguments are required for this example scripts. (Note that continuous running is not possible for this system, but it is in the library. Also, the trigger and fibre delays are set to default values in this script.) The python scripts making up the control software contain more information on the possible commands.

System commissioning

Commissioning at the University of Sussex
Initial commissioning
The nanopulser optical calibration system (serial nr OP_12_420_2_355) has been tested at the University of Sussex in February 2019, and the results of this are shown in Table 2.

The system was then shipped to Japan and tested again for functionality at the JSNS^2 lab in the KEK building at J-PARC. The system was found to be working as expected, expect for pulserhead 7. This was replaced with a spare one (programmed to reflect the position), which worked correctly.

Table 2. Results of the commissioning at the University of Sussex. The measurements are only relative: settings indicated are for which the trigger pulser and the light pulse were observed at the same time, using the specific test set-up at Sussex. The amplitude was as measured with a Hamatsu mini-PMT with mylar filter using the maximum light output setting. Note that the quantum efficiency for the UV LEDs, pulserheads 2 and 13, is much lower.

Branch	LED1				LED2				LED3			
	Pulser head	Trigger delay (ns)	Fibre length delay (ns)	Amp. (V)	Pulser head	Trigger delay (ns)	Fibre length delay (ns)	Amp. (V)	Pulser head	Trigger delay (ns)	Fibre length delay (ns)	Amp. (V)
1	1	810	21	2.7	2	830	18	1.1	3	815	7	1.8
2	4	795	7	3.5	5	810	19	5.0				
3	6	810	19	3.3	7	815	12	3.5				
4	8	800	32	5.0	9	850	8	3.0				
5	10	825	0	3.0	11	835	11	4.0				
6	12	830	17	1.5	13	830	2	0.5	14	850	4	2.5

Further commissioning
The following tasks still remain for commissioning:

- Estimate the delay needed for the system once installed.

- Confirm the settings of Table 2 and find the values for the estimated delay between optical pulse and the trigger. Try to get the all channels as close as possible. Note the (estimated) magnitude of (any) trigger jitter, if observed.

- Find the optical range for each channel - the minimal pulse is around pulse height setting 10,000. Find the actual minimal value and note the pulse integral observed in the PMT used, as well as the pulse integral when using the maximum value pulse height setting.

Analysis methods

The calibration of the system is done in the lab. Experience shows, that once installed in the experiment, things change - generally both due to changes in the system as well as due to different routing and noise environment. Therefore, the system will need to be recalibrated, or at least verified in analysis.

The following tasks are envisaged:

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-

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References

1. Ajimura, S. *et al.* Technical Design Report (TDR): Searching for a Sterile Neutrino at J-PARC MLF (E56, JSNS2). *Arxiv:1705.08629* (2017).

2. Peeters, S. J. JSNS^2 nanopulser optical calibration system. https://github.com/sjmpeeters/JSNS2_nanopulser_manual.git (2019).

3. White, R. JSNS^2 nanopulser PIC programming software and code. https://github.com/sjmpeeters/nanopulser_pic_programming.git (2019).

4. Stringer, M. Operation and performance of the JSNS^2 driver system. https://github.com/Sussex-Invisibles/JSNS2PulserControl (legacy software, for reference only) (2018).

5. Waterfield, J. JSNS^2 nanopulser PIC programming software and code. https://github.com/sjmpeeters/JSNS2_nanopulser_control_software.git (2019).

A Electronic schematics

Control box schematics
Pulserhead schematics
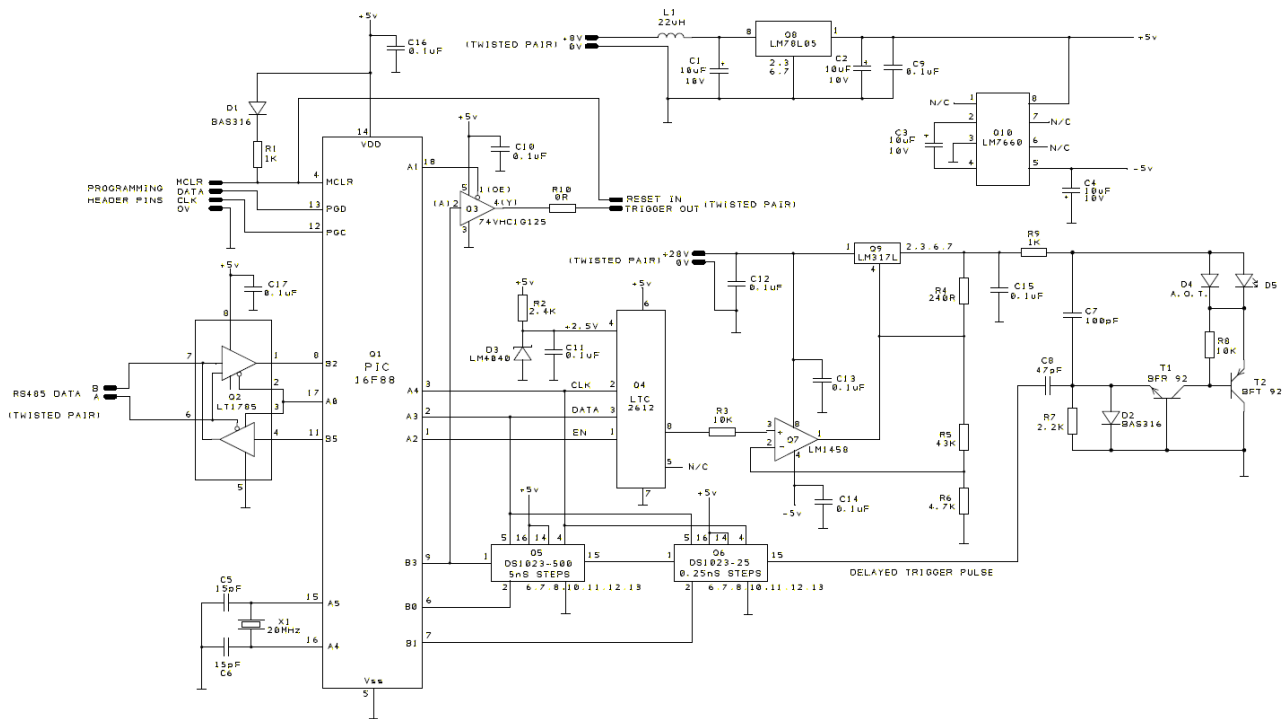
B Internal control codes

?? The control box will has an integral Raspberry Pi computer running the control program (written in python). The Raspberry Pi is accessible remotely via Ethernet. A USB port for direct control via a laptop is available.

The control codes are given here for reference (although it is recommended to use the python code available):

- G= numberlo

- H= numberhi

- I= singleselect

- L= heighthi

- M= heightlo

- P= loadheight

- a= continuous

- d= triggerdelay5ns

- e= triggerdelay025nS

- g= run

- x= stop

- R=reset

Slave boards are individually assigned a unique number in the range 1 to 26. For example: to send commands to board 5 send 'I' '5', a reply of 'B5' will be received. Subsequent commands will go to board 5 until another board is selected. A master hard reset of all slave boards is available via 'R', which will reset all the remote slave boards irrespective of the previous board selection.

Number of pulses is set with 'G' and 'H'.

Pulse amplitude is selected with 'L' and 'M' and loaded with 'P'.

A sequence is initiated with 'g' or continuous output with 'a'.

Output can be stopped at any time with 'x'.

C Pulserhead encapsulation design

??

Pulserhead base

Pulserhead tube

Ø25
Ø21
Ø14

Ø21
1

111

Internal thread to
match Bulgin PX0412:
According to
datasheet this is an
M16 x 1.5mm thread.

Thread depth of
10mm will be
sufficient.

Interface2 should
confirm this.

Ø14
Ø25

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: +/- 0.2mm ANGULAR: N/A	FINISH: Tooling marks kept to a minimum	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	1

	NAME	SIGNATURE	DATE		TITLE:
DRAWN	Antony Gibson		27/11/18		
CHK'D	Antony Gibson		27/11/18		Pulser Tube 2
APPV'D					
MFG					
Q.A			MATERIAL: Transparent Cast Acrylic	DWG NO. Pulser_Type2_Tube	A3
			WEIGHT:	SCALE:1:1	SHEET 1 OF 1