

JSNS² nanopulser optical calibration system

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ABSTRACT

This note describes the the JSNS² 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.

SJMP: Expand abstract

Version: March 20, 2019

Introduction

The JSNS² experiment¹ is a relatively small liquid scintillator detector. It relies on precise timing in order to separate the scintillation light from Cherenkov light, which is crucial for background and signal separation. This note describes the JSNS² 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 JSNS² 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 github².

SJMP: Expand introduction

Requirements

The calibration system has the following requirements:

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

This is what we provided.

SJMP: fill & add reference

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

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

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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).

This is what we provided.

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

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

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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.

System configuration

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 ‘nanopulser head’: an electronics board with digital logic and an ultra-fast LED pulser. Each string has either two or three nanopulser heads. In total, there are twelve nanopulser heads with a 420 nm LED and two nanopulser heads 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 JSNS² nanopulser optical calibration system, up to the junction box.

Branch	Flange	Cable length (m)	Pulserhead		Cable length (m)	Pulserhead		Cable length (m)	Pulserhead	
			ID	λ_{LED} (nm)		ID	λ_{LED} (nm)		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

Furuta-san: picture of LED mounting board

Furuta-san: coordinates of LEDs and associated PMT IDs (if available?)

Hino-san: picture of cable flange design

SJMP: Wavelength spectra for 420 nm and 355 nm LEDs

SJMP: Angular distribution for 420 nm and 355 nm LEDs

System performance

Nanopulser head

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.

RW: detailed schematic of the nanopulser head.

Nanopulser head programming

The nanopulser heads 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

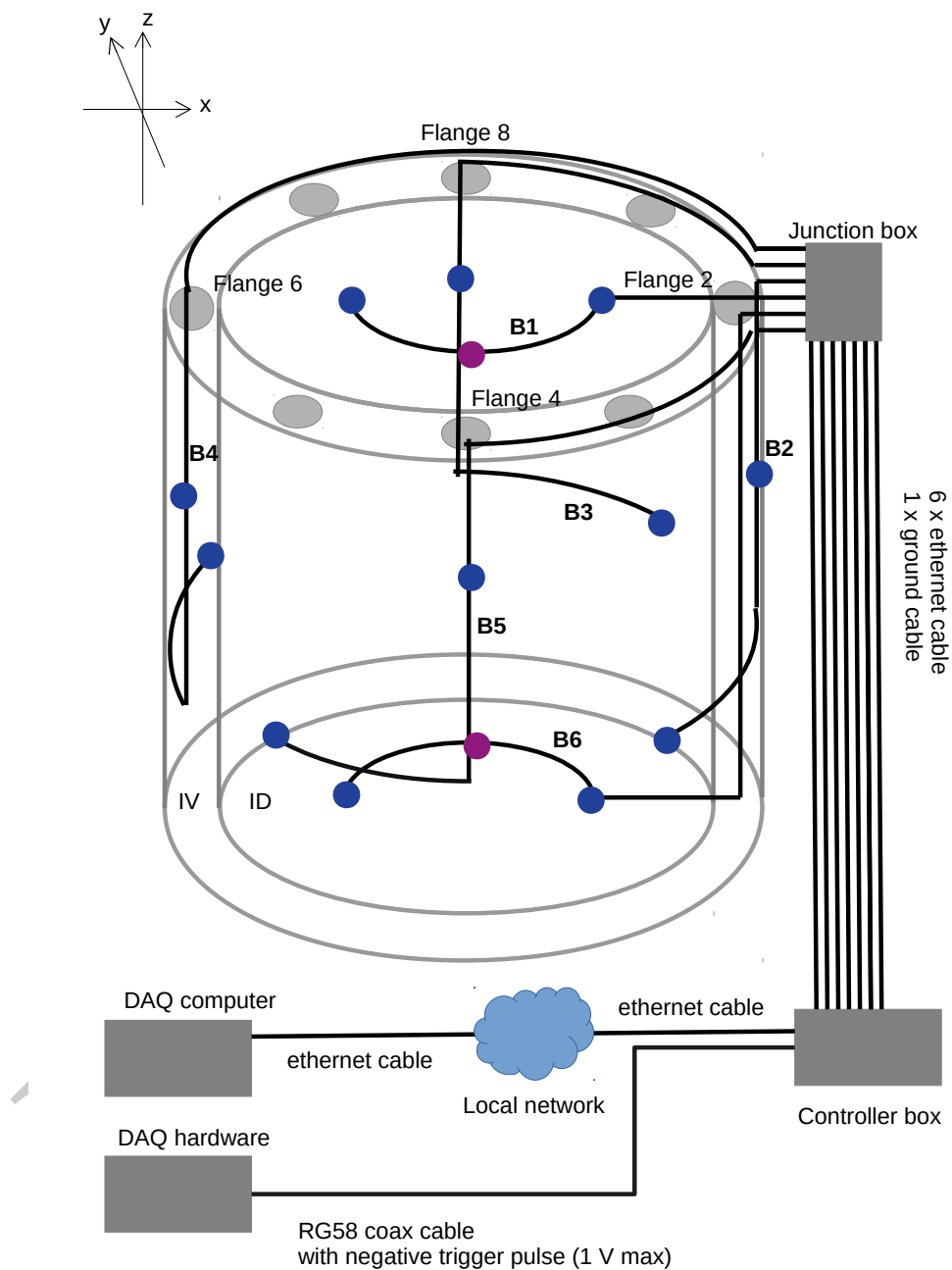


Figure 1. A schematic overview of the nanopulser optical calibration system. The (two) purple points indicate the position of the nanopulser heads (LED driver boards) with a 355 nm LED, the (twelve) blue points indicate nanopulser heads with a 420 nm LED. All LEDs point inwards. The numbers B1-B6 indicated the different branches. IV is the Inner Veto volume and ID is the Inner Detector volume.

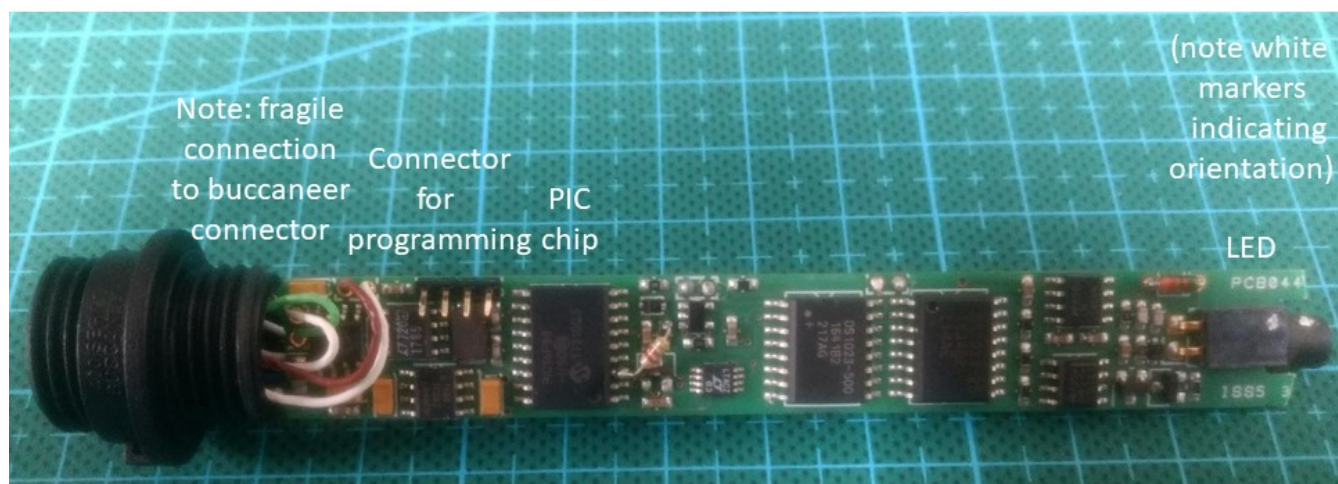


Figure 2. Photo of the a nanopulser head, outside of its acrylic housing, with the main components indicated.



Figure 3. Rendered drawing of the acrylic housing, with an O-ring (black in this image, but white in reality).

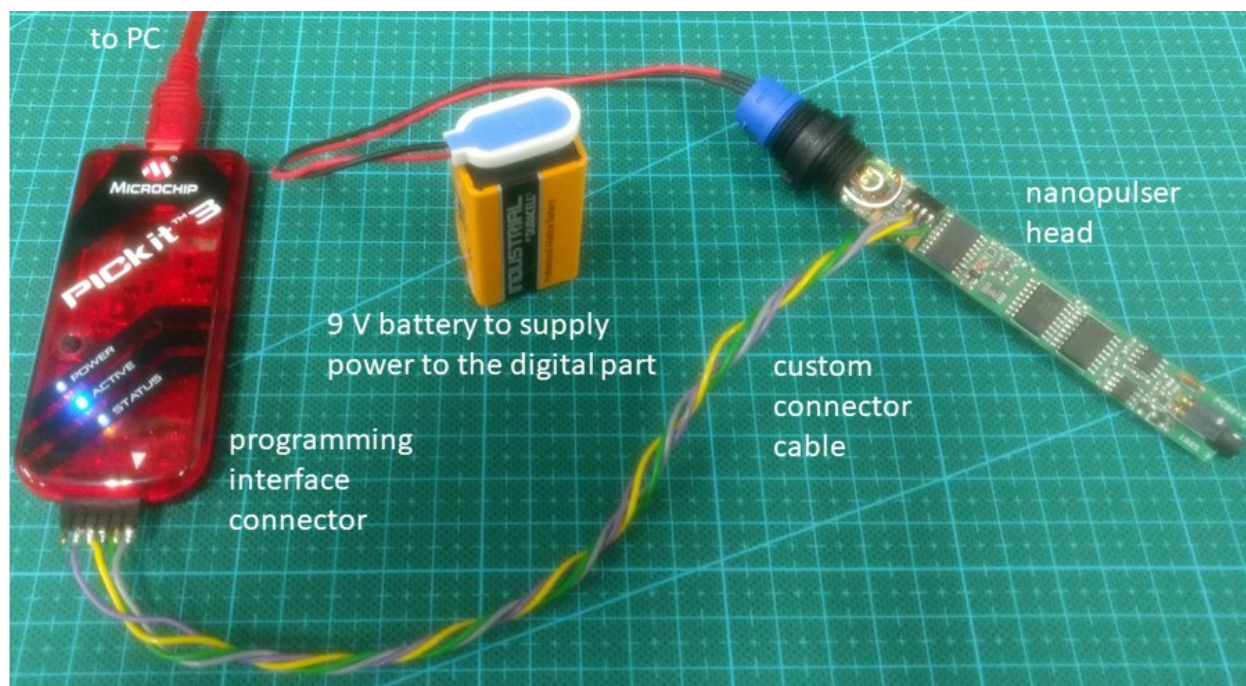


Figure 4. The pulser head programming set-up (window10 computer needed, not shown here).

the PIC chip¹. The code is loaded onto the PIC chip via a commercial interface (microchip PICKit3) with a custom cable to the nanopulser head. 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 nanopulser head. The connector on the nanopulser head is slanted an slightly bend, to make it fit into the nanopulser head's acrylic housing. Therefore, take extra care when connecting to make sure a good contact is make.

The software for the nanopulser head programming can be found on github³. 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 nanopulser heads was documented on github⁴, and is summarised in Figure 5.

SJMP: insert pressure test results

Nanopulser control box

RW,SJMP: add details about the voltages (9 V, 24 V, tbc, which is which?)

RW,SJMP: check control lights and add information on meaning.

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).

RW: details about the delay settings

RW: detailed schematic of the control box

¹Make sure the battery has enough power left to power the PIC chip.

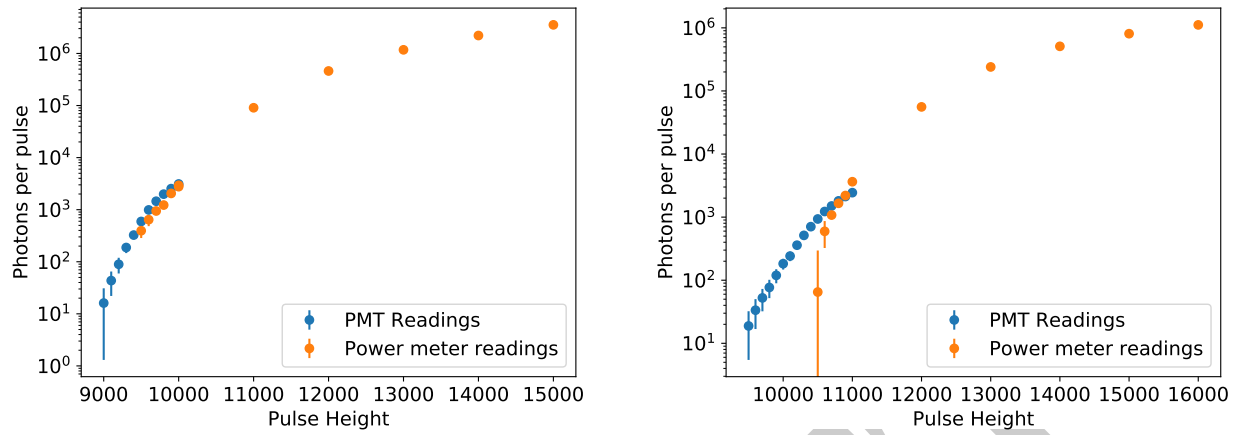


Figure 5. The optical output of the pulserheads with 420 nm LEDs (left) and 355 nm LEDs (right). The x-axis is the digital setting used for the measurements. Most of the range is observed with a calibrated optical power meter. At the low end, however, this device was not sensitive enough and a careful extrapolation based on measurement using a PMT is shown. T

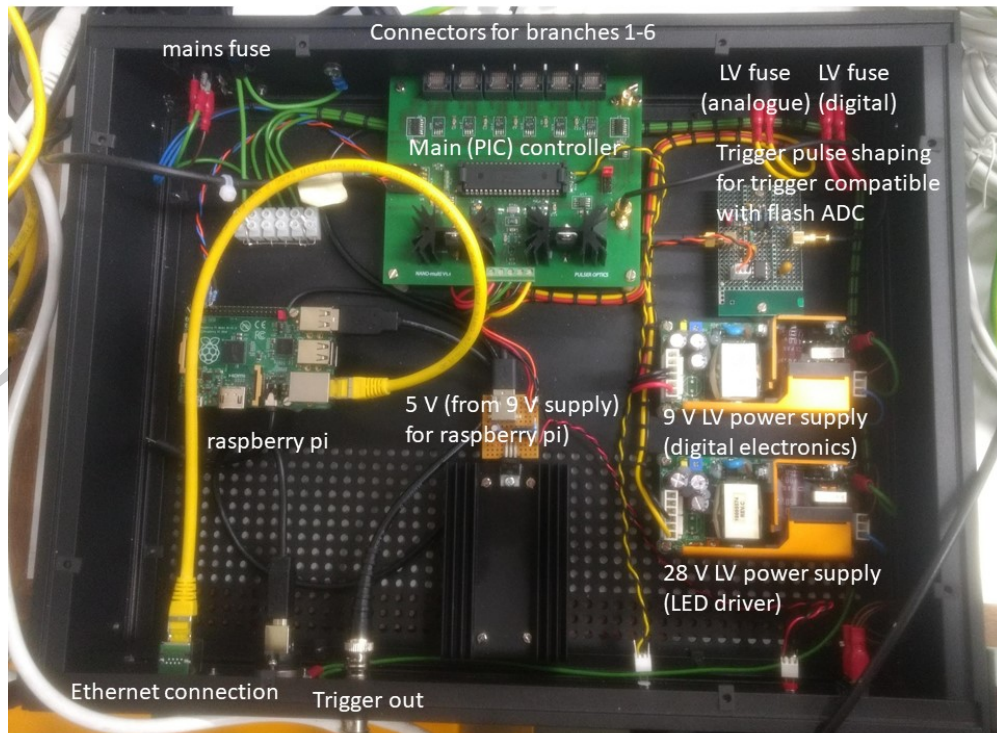


Figure 6. Photo of the controlbox during commissioning at the University of Sussex, with the main components indicated. Note that all the fuses and connections can be accessed from the outside.

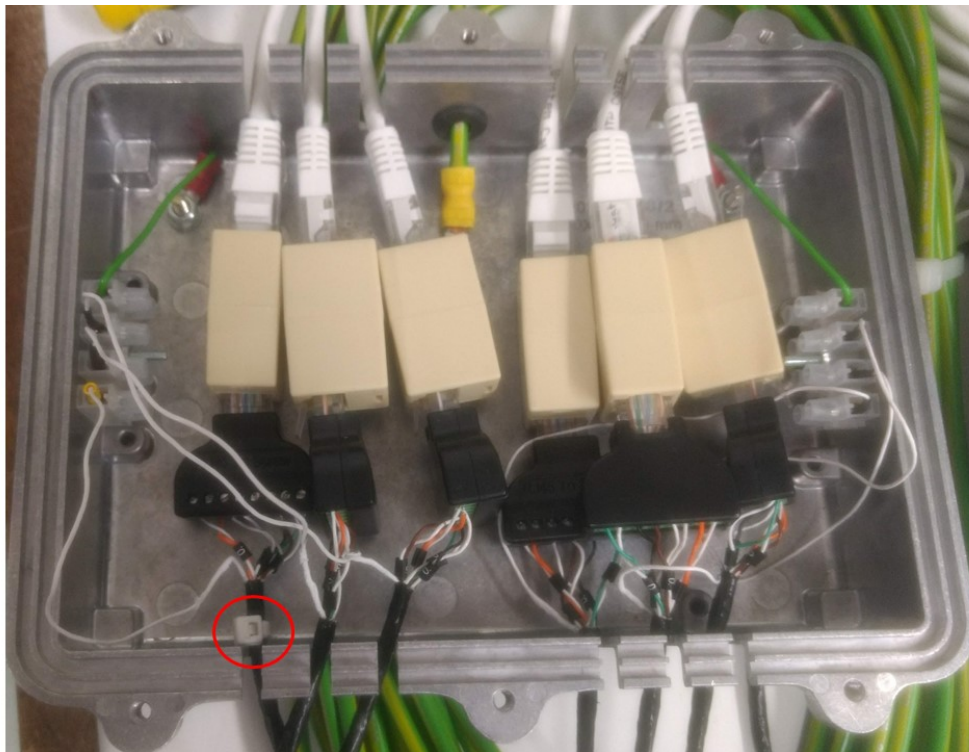


Figure 7. Photo of the junction during commissioning at the University of Sussex. The ethernet cables on the top connect to the back of the control box (this is labeled 1-6 for the branch numbers). The cables coming from the connector need to be wired to the black eight-way connectors in the pictures (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).

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. Accidental hot-swapping can result in one of the fuses blowing.

SJMP: insert cable design, aging results

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. Not that the (longer) ground cable also needs to be connected to the junction box chassis (see Figure 7).

Control software

The software is kept in a github repository⁵. (An older, deprecated, version with documentation is also kept in a different github repository⁴, for reference only).

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

SJMP: check n pulse



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

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 JSNS² lab in the KEK building at J-PARC. The system was found to be working as expected, except 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.

Branch	LED1				LED2				LED3			
	Pulser head	Trigger delay	Fibre length delay	Amp. (V)	Pulser head	Trigger delay	Fibre length delay	Amp. (V)	Pulser head	Trigger delay	Fibre length delay	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:

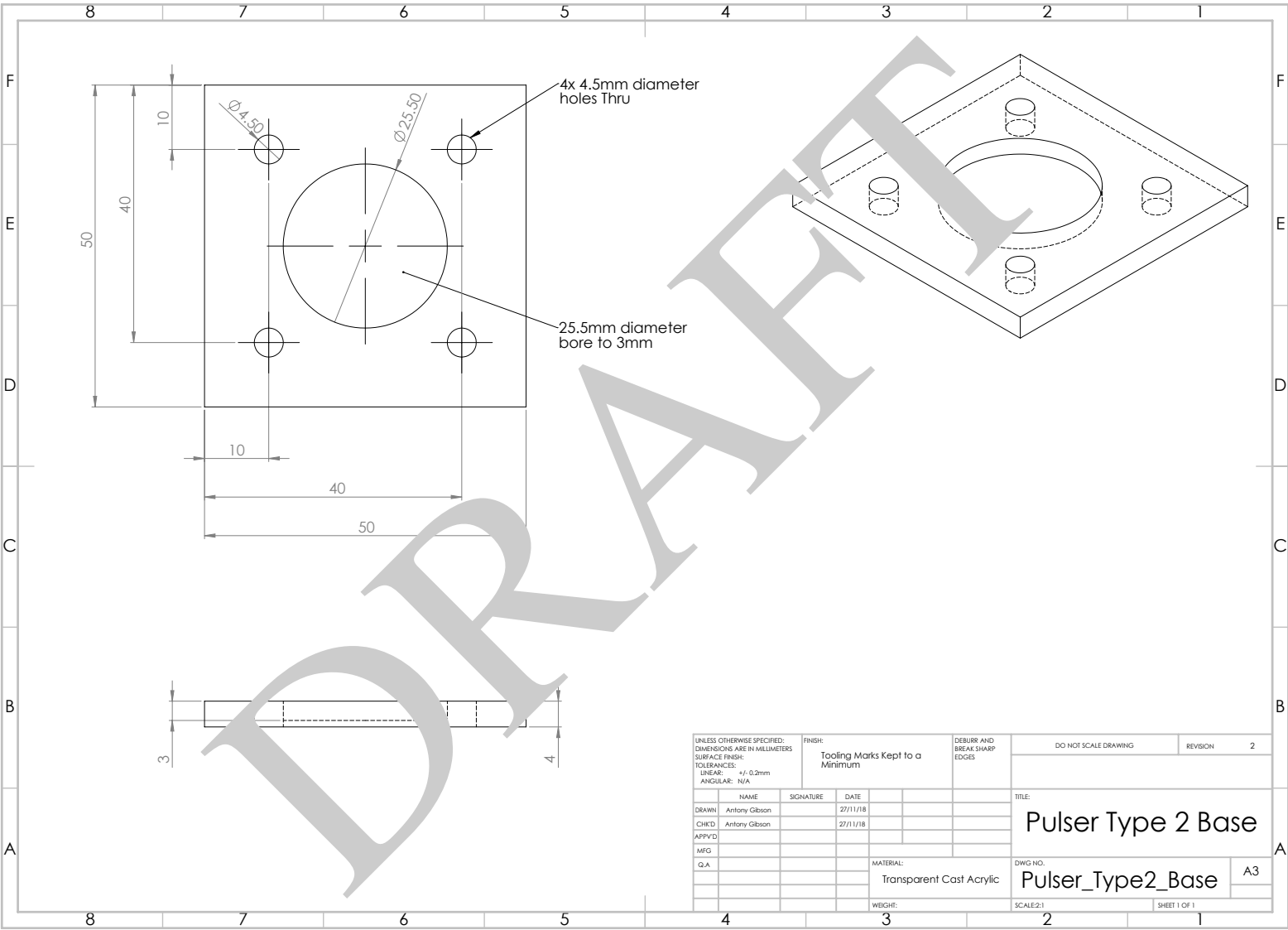
- Estimate the delay needed for the system once installed.

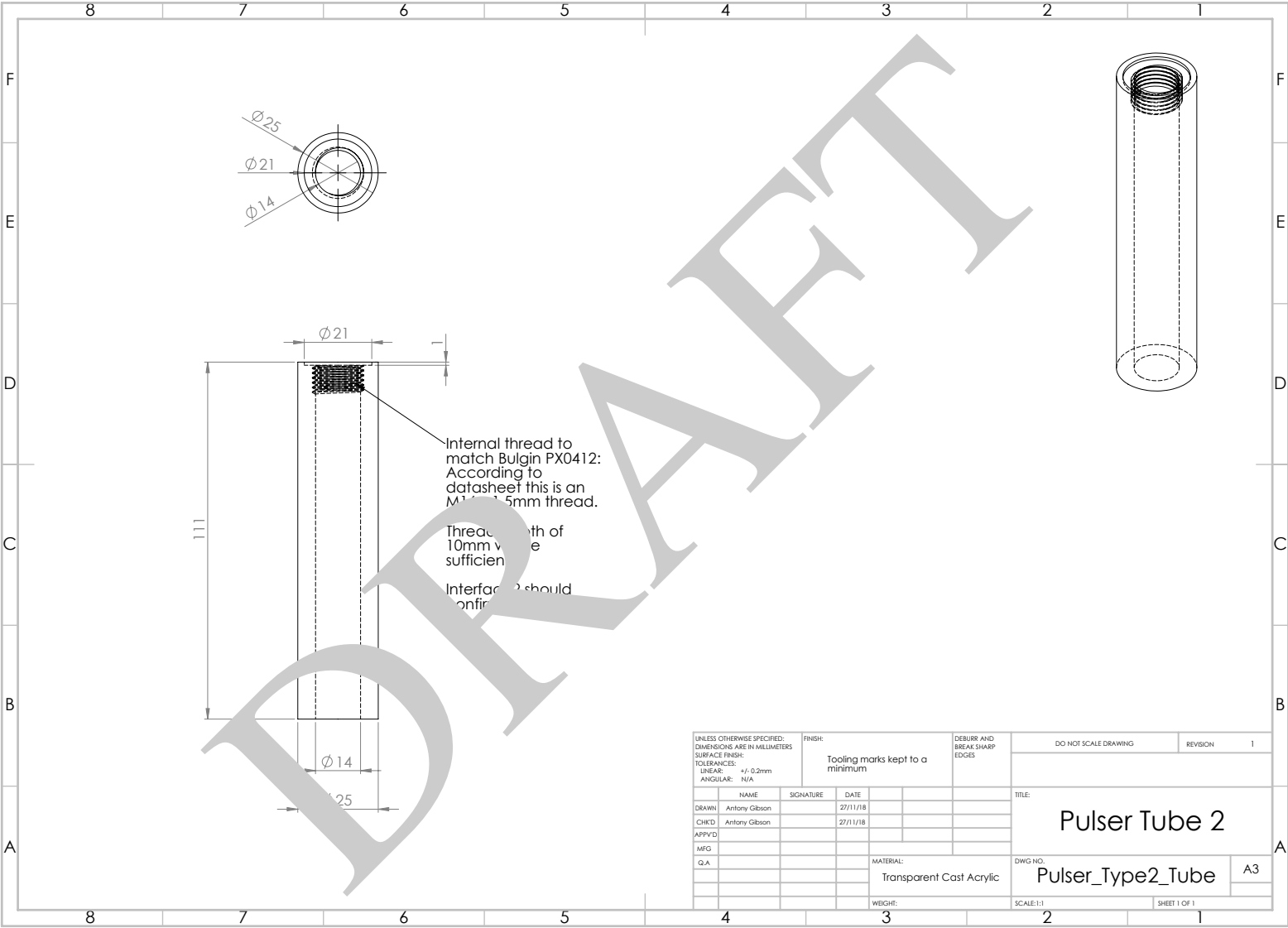
- Confirm the settings of Table 2 and find the values for the estimated delay between optical pulse and the trigger. Try to get the all channels as close as possible. Note the (estimated) magnitude of (any) trigger jitter, if observed.
- Find the optical range for each channel - the minimal pulse is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

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. JSNS² nanopulser optical calibration system. https://github.com/sjmpeeters/JSNS2_nanopulser_manual.git (2019).
3. White, R. JSNS² nanopulser PIC programming software and code. https://github.com/sjmpeeters/nanopulser_pic_programming.git (2019).
4. Stringer, M. Operation and performance of the JSNS² driver system. <https://github.com/Sussex-Invisibles/JSNS2PulserControl> (2018).
5. Waterfield, J. JSNS² nanopulser PIC programming software and code. https://github.com/sjmpeeters/JSNS2_nanopulser_control_software.git (2019).

DRAFT





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		
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DRAWN: Anthony Gibson				27/11/18								<div>Pulser Tube 2</div>	
CH'D: Anthony Gibson				27/11/18									
APP'VD													
MFG													
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162	<input type="checkbox"/> SJMP: fill & add reference	2
163	<input type="checkbox"/> Furuta-san: picture of LED mounting board	2
164	<input type="checkbox"/> Furuta-san: coordinates of LEDs and associated PMT IDs (if available?)	2
165	<input type="checkbox"/> Hino-san: picture of cable flange design	2
166	<input type="checkbox"/> SJMP: Wavelength spectra for 420 nm and 355 nm LEDs	2
167	<input type="checkbox"/> SJMP: Angular distribution for 420 nm and 355 nm LEDs	2
168	<input type="checkbox"/> RW: detailed schematic of the nanopulser head.	2
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173	<input type="checkbox"/> RW: detailed schematic of the control box	5
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176	<input type="checkbox"/> AG: check drawings	10