Application Note 01 – HAM PMT Base

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Revision History

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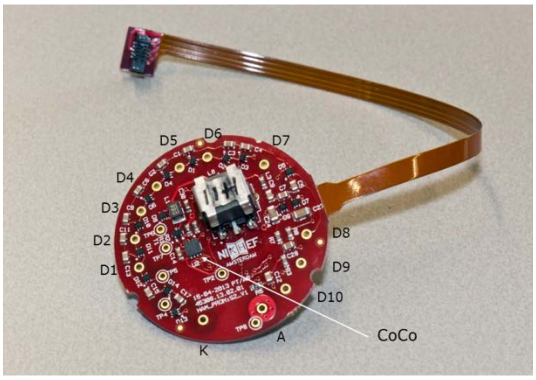
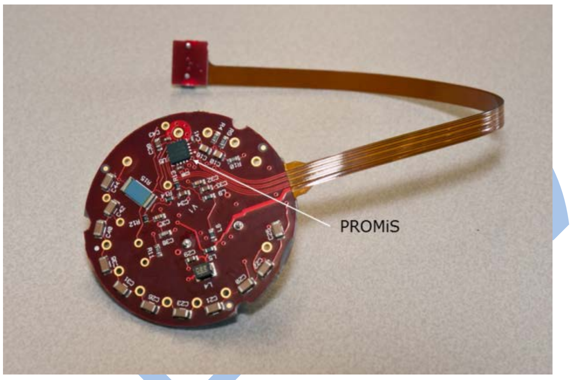
PMT Base Description

The PMT Base [1] is a low power, small area, single supply PCB that can be plugged-in on a PMT as shown in Figure 1. A Cockroft-Walton voltage multiplier circuit is designed, using discrete components, that generates the required high-voltage for the PMT, from a single 3.3V supply.





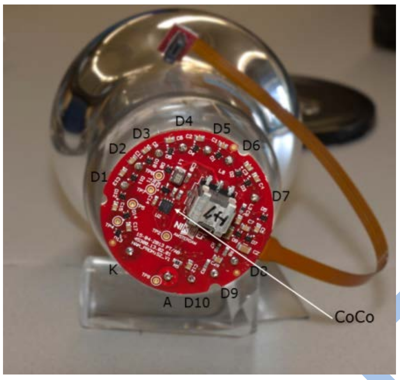


Figure 1 Top : PMT Base top view (L), PMT Base bottom view (R). Bottom : PMT base on a HAMAMATSU PMT (type R12199-02)

PROMiS Description

PROMiS [2][3] is a mixed signal chip that can read out a Photo Multiplier Tube and is optimized for single photon detection. The chip can be addressed using slow control I2C protocol. PROMiS gives the ToT information on the LVDS pins. The PMT signal is amplified and then discriminated against an adjustable threshold level. This signal is then sent as LVDS signals. The chip works on a single 3.3V supply. A block diagram is shown in Figure 2. For more information, refer to PROMiS datasheet.

PROMiS Block Diagram

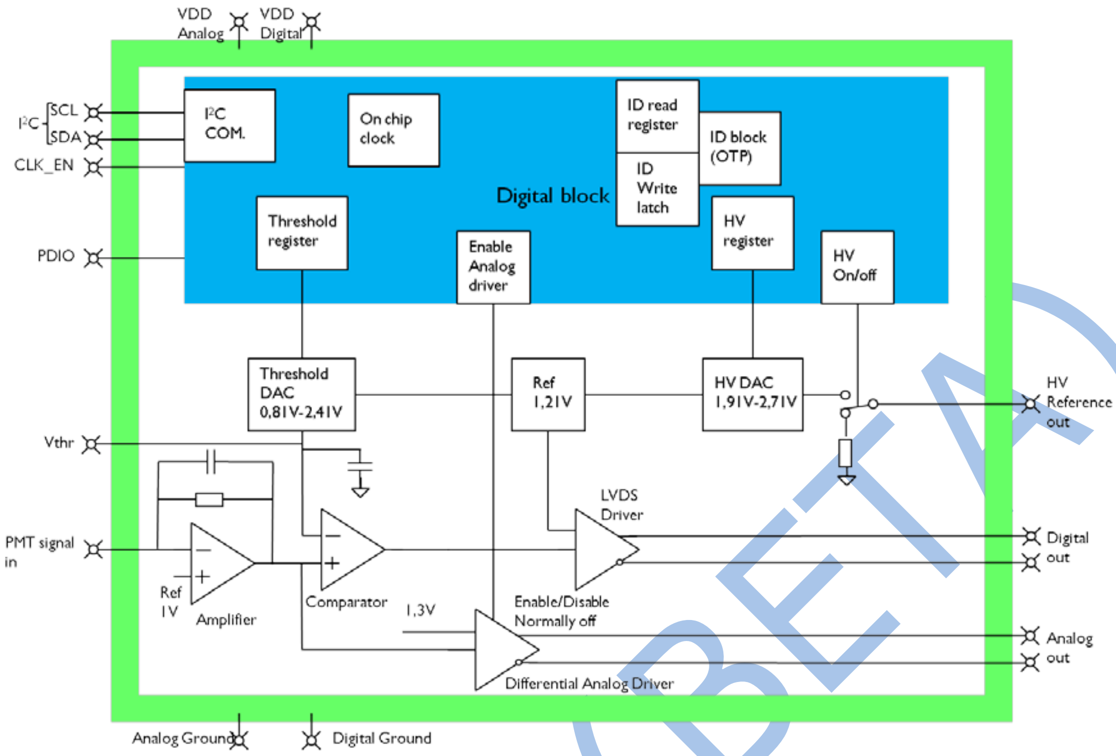


Figure 2 Block Diagram of PROMiS.

CoCo Description

CoCo [3] is an analog chip that can regulate the frequency of the output pulses based on the feedback and is optimized to be used in the feedback of the Cockroft-Walton Multiplier. The CWM is used to drive the dynodes of a PMT. CoCo gives out 6.5 us pulses whose frequency can be regulated. The width of these pulses can also be controlled. The chip works on a single 3.3V supply. A block diagram is shown in Figure 3. For more information, refer to CoCo datasheet.

CoCo Block Diagram

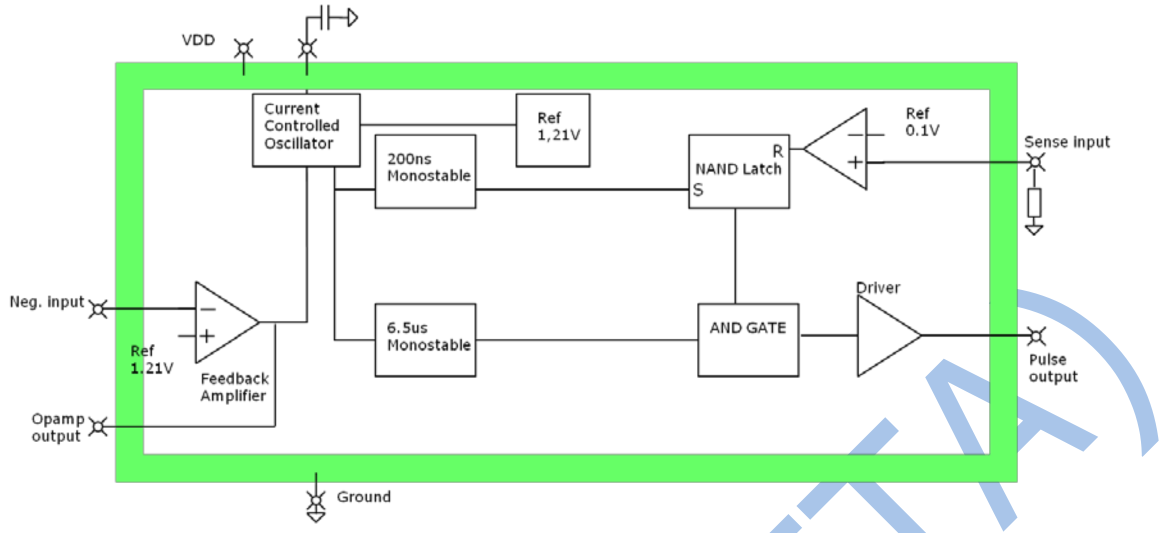


Figure 3 Block diagram of CoCo.

I²C Communication

The slow control of PROMiS ASIC is done via I²C (http://en.wikipedia.org/wiki/I%C2%B2C). The PROMiS acts as a slave-only with its 7 bit address "0110000". There are 16 registers with HEX pointers ranging from 0x0 until 0xF, of which, only 11 are accessible. Following is the write and read format of the I²C registers. (Also shown in Table 1)

Pointer 0 – Comparator Threshold register , threshold level of comparator can be set.

Pointer 1 – High Voltage DAC register, the desired level of high voltage can be set.

Pointer 2 - Control register, a few analog/digital functionality of the chip can be controlled.

Pointer 3 – Reserved.

Pointer 4 – Desired ID data register, Lowest byte of the desired ID to be written in the latch of PPTRIM.

Pointer 5 – Desired ID data register, Middle byte of the desired ID to be written in the latch of PPTRIM.

Pointer 6 – Desired ID data register, Highest byte of the desired ID to be written in the latch of PPTRIM.

These 3 bytes will be burnt finally in the One Time Programmable memory – (PPTRIM) also called PROM.

Pointer 7 – Reserved.

Pointer 8 (Read only) – Actual ID/ Burnt data of PPTRIM/PROM, Lowest byte of the ID .

Pointer 9 (Read only) – Actual ID/ Burnt data of PPTRIM/PROM, Middle byte of the ID.

Pointer 10 (Read only) – Actual ID/ Burnt data of PPTRIM/PROM, Highest byte of the ID.

For example, if we would like to address the HVDAC register, then we first address the PROMiS ASIC by its 7 bit slave address "0110000" and then Pointer 1 and then the data for the comparator threshold register. The pointer is automatically incremented. The next data byte (if supplied) is written into Pointer 2. We can either choose to stop the I^2C protocol here or go on by issuing a repeated start condition of I^2C.

Write	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Pointer 0	Cmprtr Threshold 7	Cmprtr Threshold 6	Cmprtr Threshold 5	Cmprtr Threshold 4	Cmprtr Threshold 3	Cmprtr Threshold 2	Cmprtr Threshold 1	Cmprtr Threshold 0
Pointer 1	HV DAC 7	HV DAC 6	HV DAC 5	HV DAC 4	HV DAC 3	HV DAC 2	HV DAC 1	HV DAC 0
Pointer 2	NC	Ana_buf_on_off	PROM burn	100mA OK	Analog Chain Test	HV_on_off	Latch Write	PROM Read
Pointer 3	---	---	---	---	---	---	---	---
Pointer 4	PROG data 7	PROG data 6	PROG data 5	PROG data 4	PROG data 3	PROG data 2	PROG data 1	PROG data 0
Pointer 5	PROG data 15	PROG data 14	PROG data 13	PROG data 12	PROG data 11	PROG data 10	PROG data 9	PROG data 8
Pointer 6	PROG data 23	PROG data 22	PROG data 21	PROG data 20	PROG data 19	PROG data 18	PROG data 17	PROG data 16
Read	**Bit 7**	**Bit 6**	**Bit 5**	**Bit 4**	**Bit 3**	**Bit 2**	**Bit 1**	**Bit 0**
Pointer 0	Cmprtr Threshold 7	Cmprtr Threshold 6	Cmprtr Threshold 5	Cmprtr Threshold 4	Cmprtr Threshold 3	Cmprtr Threshold 2	Cmprtr Threshold 1	Cmprtr Threshold 0
Pointer 1	HV DAC 7	HV DAC 6	HV DAC 5	HV DAC 4	HV DAC 3	HV DAC 2	HV DAC 1	HV DAC 0
Pointer 2	NC	Ana_buf_on_off	PROM burn	100mA OK	Analog Chain Test	HV_on_off	Latch Write	PROM Read
Pointer 3	0	0	0	0	0	0	0	0
Pointer 4	PROG data 7	PROG data 6	PROG data 5	PROG data 4	PROG data 3	PROG data 2	PROG data 1	PROG data 0
Pointer 5	PROG data 15	PROG data 14	PROG data 13	PROG data 12	PROG data 11	PROG data 10	PROG data 9	PROG data 8
Pointer 6	PROG data 23	PROG data 22	PROG data 21	PROG data 20	PROG data 19	PROG data 18	PROG data 17	PROG data 16
Pointer 7	0	0	0	0	0	0	0	0
Pointer 8	PROM data 7	PROM data 6	PROM data 5	PROM data 4	PROM data 3	PROM data 2	PROM data 1	PROM data 0

Pointer 9	PROM data 15	PROM data 14	PROM data 13	PROM data 12	PROM data 11	PROM data 10	PROM data 9	PROM data 8
Pointer 10	PROM data 23	PROM data 22	PROM data 21	PROM data 20	PROM data 19	PROM data 18	PROM data 17	PROM data 16

Table 1: I2C registers for I2C communication.

I^{2}C communication can be achieved by using a simple Labview program (shown in Figure 4) and USB I^{2}C interface. http://sine.ni.com/nips/cds/view/p/lang/nl/nid/202368 is one such example. Please make sure to recognize the interface in the Settings tab as described in the document of the labview program.

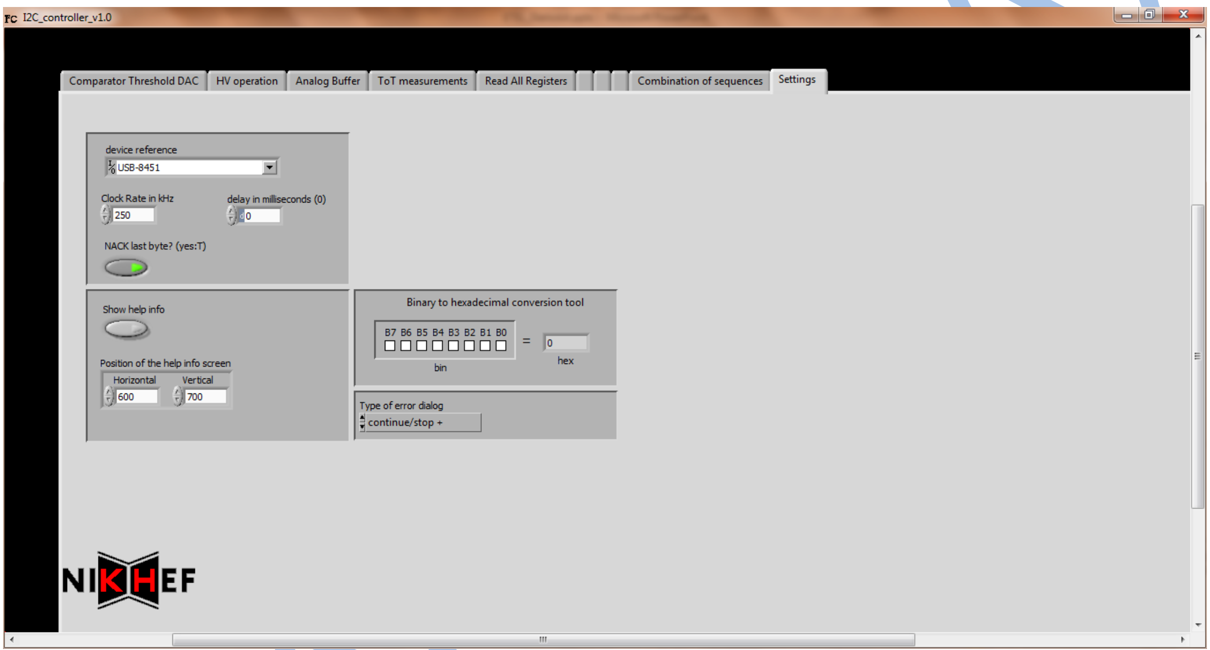


Figure 4 Labview program for USB I^{2}C interface communication.

Readout Board Description

A readout board has been designed that can route the signals from the PMT base to a measurement equipment, for example an oscilloscope. The backside of the board contains pull up resistors for the I^{2}C and termination resistor for the LVDS. It also has decoupling capacitors for the analog buffer pins. On the topside of the board, there are through hole LEMO connectors for LVDS and analog buffer. The PMT base can be connected to a TEM connector on the topside of the Readout Board as shown in Figure 5. External power supply connections and the I^{2}C connections are also shown. The schematic of the Readout Board is shown in Figure 6.

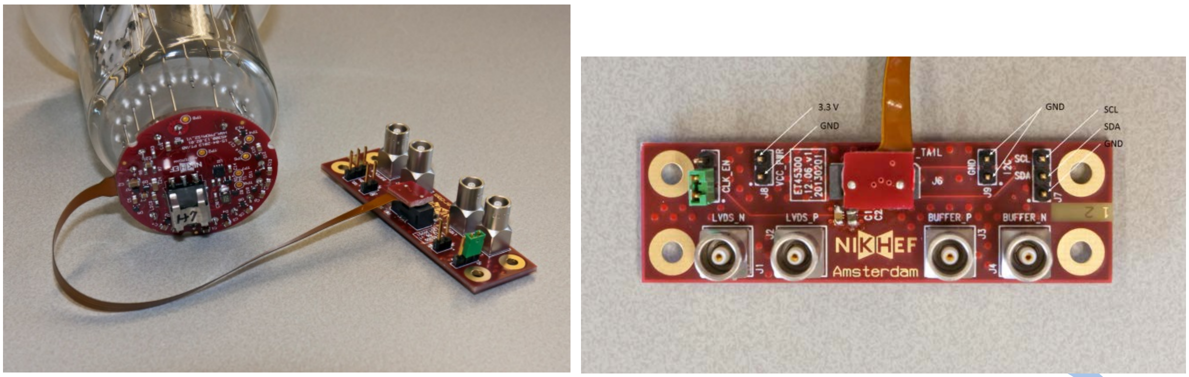


Figure 5 PMT with the Base connected to the Readout Board (L). External connection details on the readout board (R).

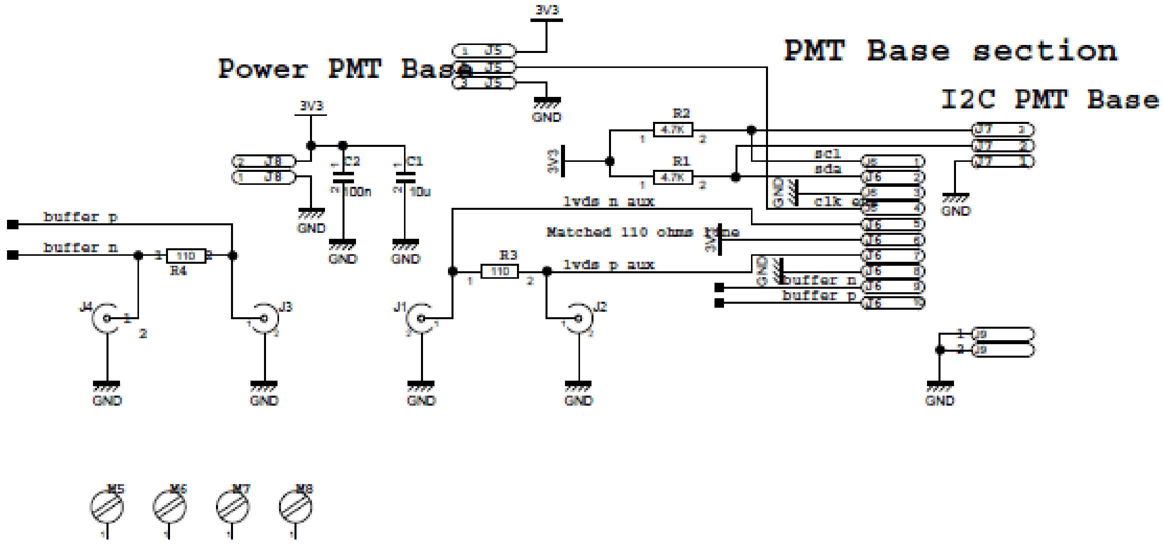


Figure 6 Schematic of the Readout Board.

Functionality

Digital Part

I^{2}C slave block

1. Use nominal 3.3 V supply.
2. Enable clock to the chip by asserting a High on the Clock_enable pin (PIN12).
3. Use the I^{2}C protocol (explained in I^{2}C communication section) to communicate with PROMiS.

Analog Part

Setting High Voltage

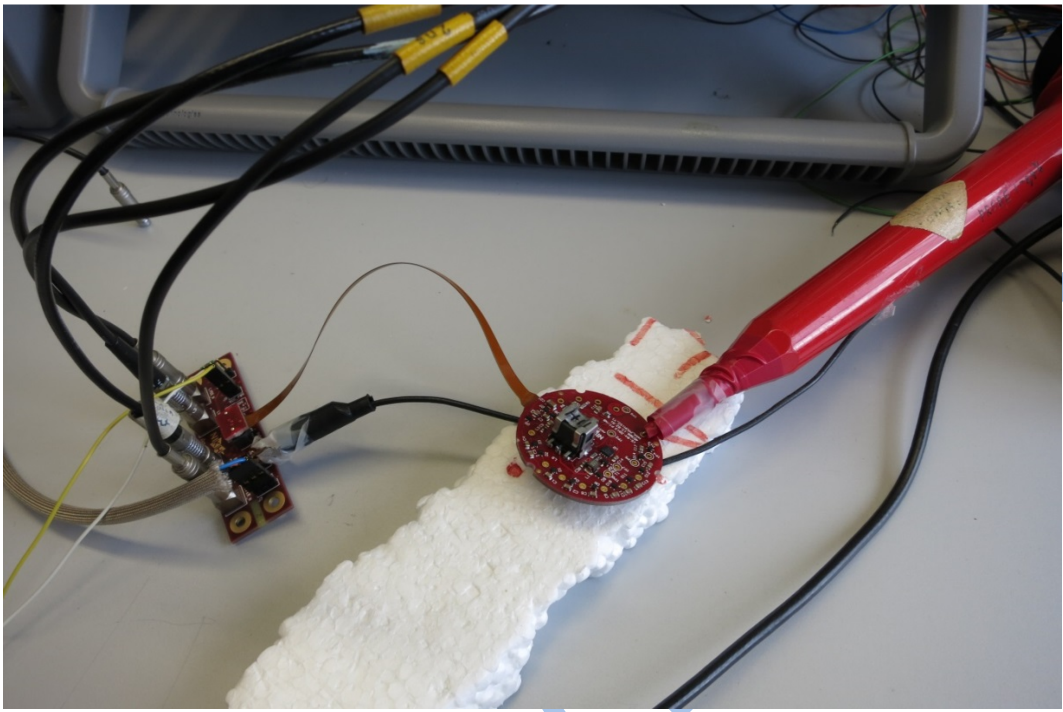


Figure 7 Measuring HV on the cathode using a HV probe.

1. Use nominal 3.3 V supply.

2. Communicate using I^2C values to make high the 'HVonoff' bit in the control register i.e. set control register (Pointer2) to 0x04 hex value using I2C (Figure 7 and Figure 8).

3. Communicate using I^2C values to set the HV DAC register (Pointer1) to any hex value between 0x00 and 0xFF.

4. 0x00 corresponds to -700V on the last dynode and 0xFF corresponds to -1500V. The MSD (Most Significant Digit) corresponds to -50V. (Table 2)

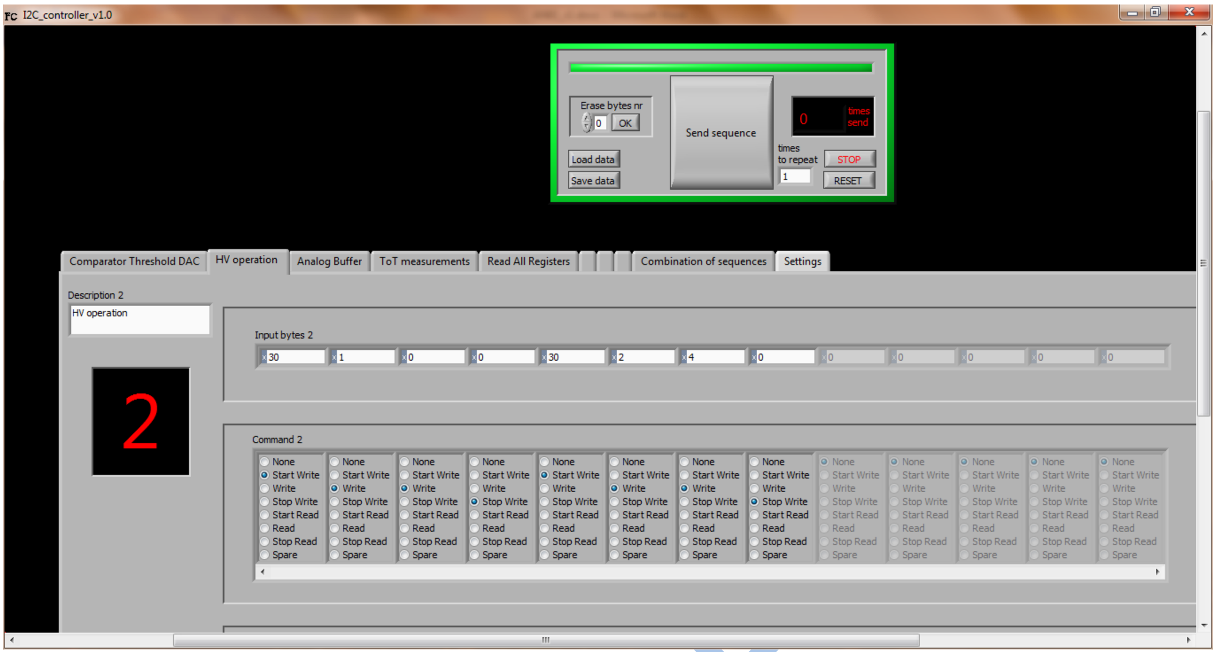


Figure 8 Labview program to turn on the HV and set the HV.

Note : Without the HVonoff bit being set, the HVDAC register values do not take effect.

⚠ The HV circuit needs to be fully discharged (on all dynodes and cathode) using a high-ohmic resistor or a probe that can withstand HV etc. after the measurements.

HVDAC code	Voltage on cathode (in V)
0x00	-692
0x10	-742
0x20	-792
0x30	-842
0x40	-892
0x50	-942
0x60	-992
0x70	-1042
0x80	-1092
0x90	-1142
0xA0	-1192
0xB0	-1242

0xC0	-1292
0xD0	-1342
0xE0	-1389
0xF0	-1440
0xFF	-1492

Table 2: HVDAC code and the corresponding voltage on the Cathode.

Setting Comparator threshold

1. Use nominal 3.3 V supply.
2. Communicate using I^2C values to set the Comparator Threshold DAC register (Pointer0) to any hex value between 0x00 and 0xFF. (Figure 9)
3. 0x00 corresponds to 0.8V on the comparator and 0xFF corresponds to 2.4V. The MSD (Most Significant Digit) corresponds to 0.1V.

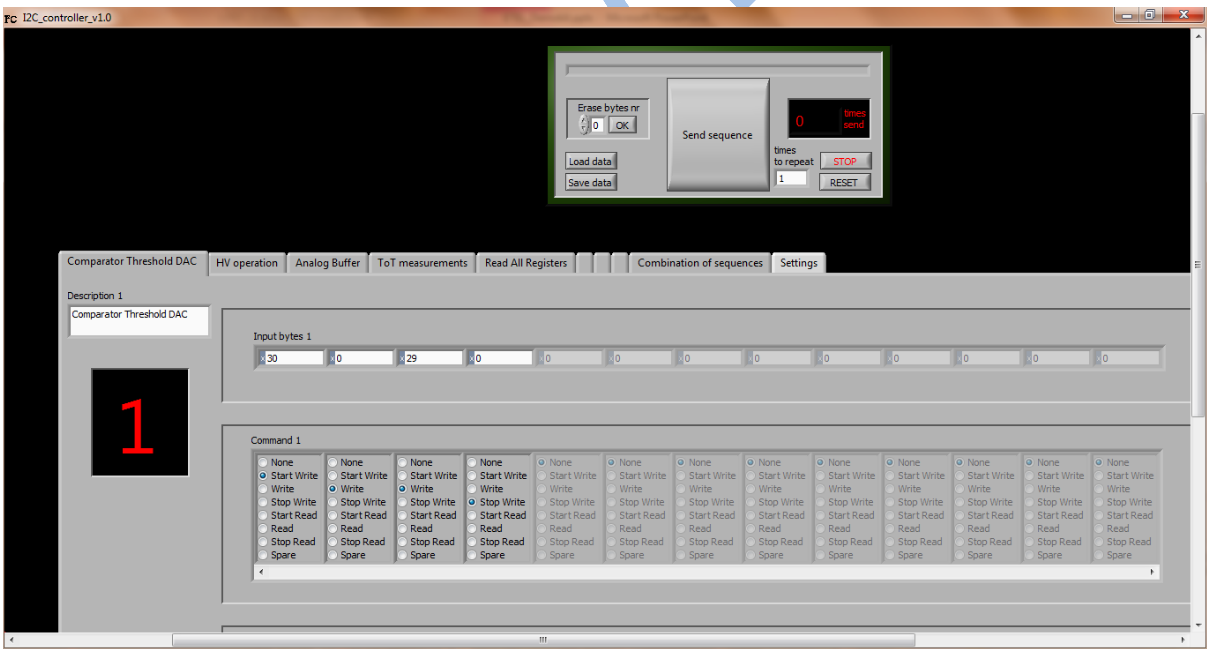


Figure 9 Labview program to set the comparator threshold value.

ToT (Time over Threshold) Measurements

1. Use nominal 3.3 V supply.
2. Set Comparator Threshold DAC register (Pointer0) to required value using I^2C. For example set comparator to 0x2B. (Figure 10)

3. Set HVDAC register (Pointer1) to required value using I^2C to set an appropriate gain on the PMT.
4. Set the HVonoff bit in the control register using I^2C. This step should set the HV on all the dynodes of the PMT.
5. If a single photon source is shone on the PMT (in a dark environment), a ToT of ~33 ns (for a gain of 3E6 and threshold DAC set at 0x27) can be measured on the LVDS pins.

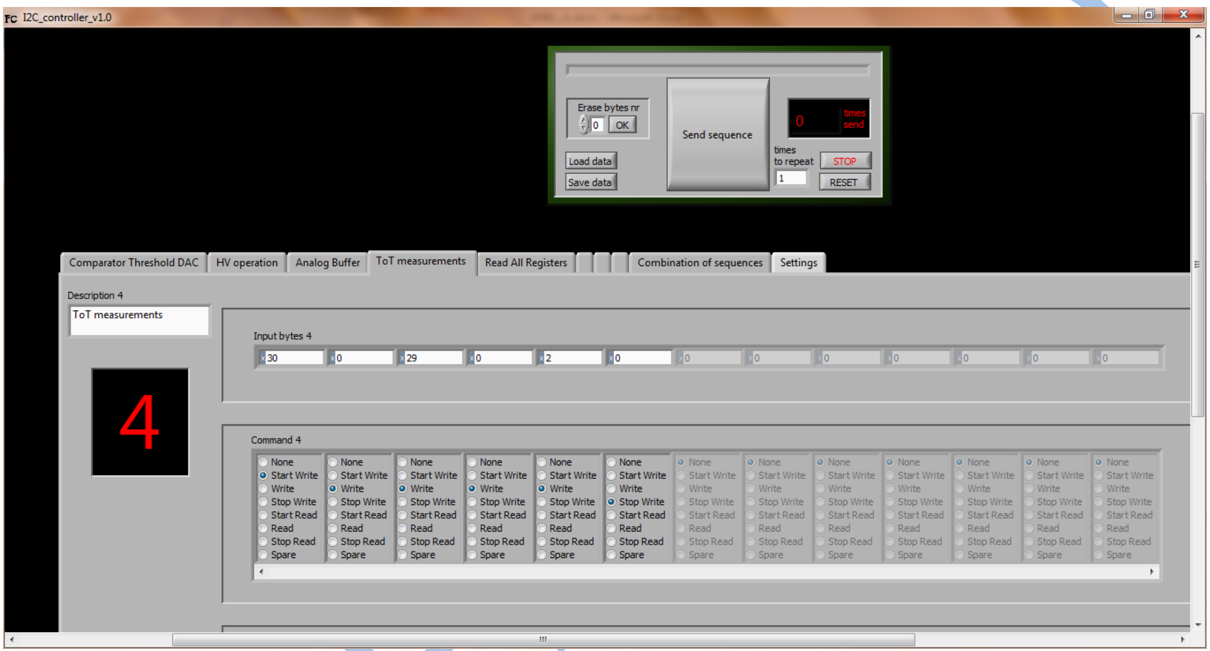


Figure 10 Labview program to measure ToT.

For ease of measurements LEMO connectors are made available on the Readout Board. Sample waveforms are shown in figures below. For timing related information, it is easy to connect cables. If the measurements are made on an oscilloscope, the channel should be on DC high impedance mode. For more precise measurements, it is advised to use probes. For example, a single photon on a PMT operating at a gain of 1E6 is equivalent to 160 fC of charge. This situation can be mimicked by using a pulse generator connected in series with a 3.3 pF capacitor to apply the charge. An input of 50 mV will now correspond to 1 photon equivalent charge from a PMT operating at a gain of 1E6.Table 3 shows some ToT measurement results

Number of Photons	Input Charge (fC)	ToT (ns)
1	160	22
2	320	30

3	480	33
4	640	36
5	800	38

Table 3: ToT values for various input charge. Comparator Threshold DAC set at 0x27

Analog Pulse Measurements

The preamplifier output can be observed on the analog buffer pins. The analog buffer outputs are routed to pins in the connector. For ease of measurements LEMO connectors are made available on the Readout Board. Sample waveforms are shown in figures below. For timing related information, it is easy to connect cables. If the measurements are made on an oscilloscope, the channel should be on DC 50 Ω mode.

1. Use nominal 3.3 V supply.
2. Set HVDAC register (Pointer1) to required value using I²C to set an appropriate gain on the PMT (Figure 11). ⚠
3. Set the HVonoff bit in the control register using I²C. This step should set the HV on all the dynodes of the PMT (Figure 11). ⚠
4. If a single photon source is shone on the PMT (in a dark environment), a ToT of ~33 ns (for a gain of 3E6 and threshold DAC set at 0x27) can be measured on the LVDS pins.

Figure 12 shows some typical measurements.

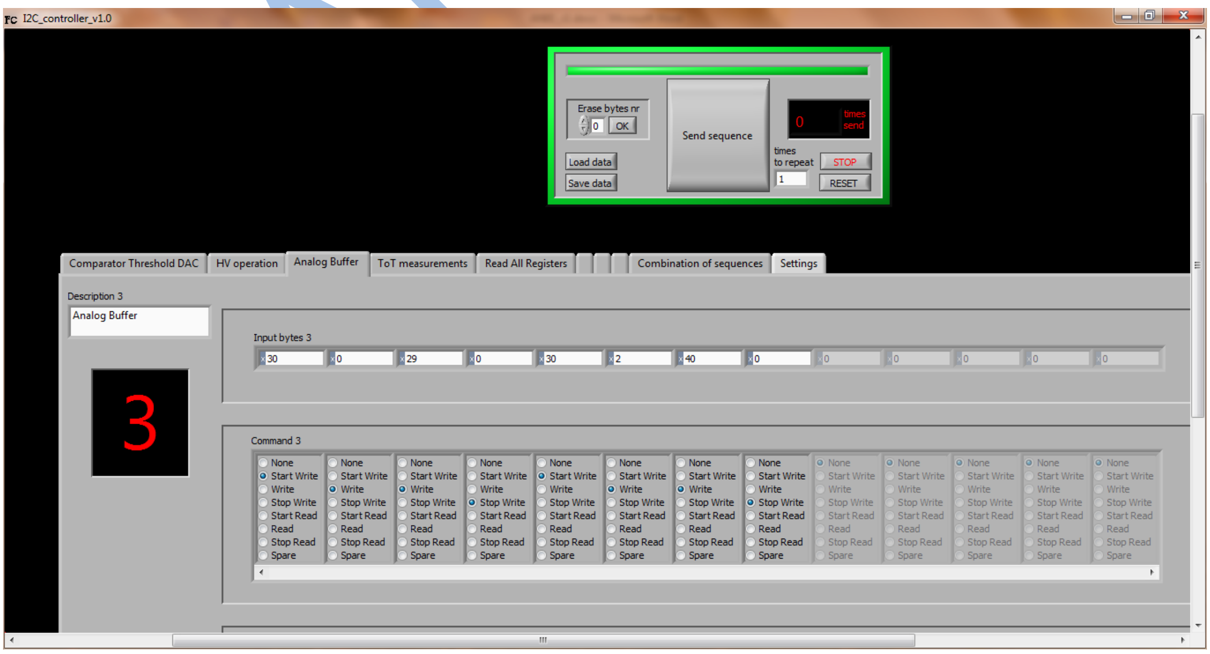


Figure 11 Labview program to set the analog buffer.

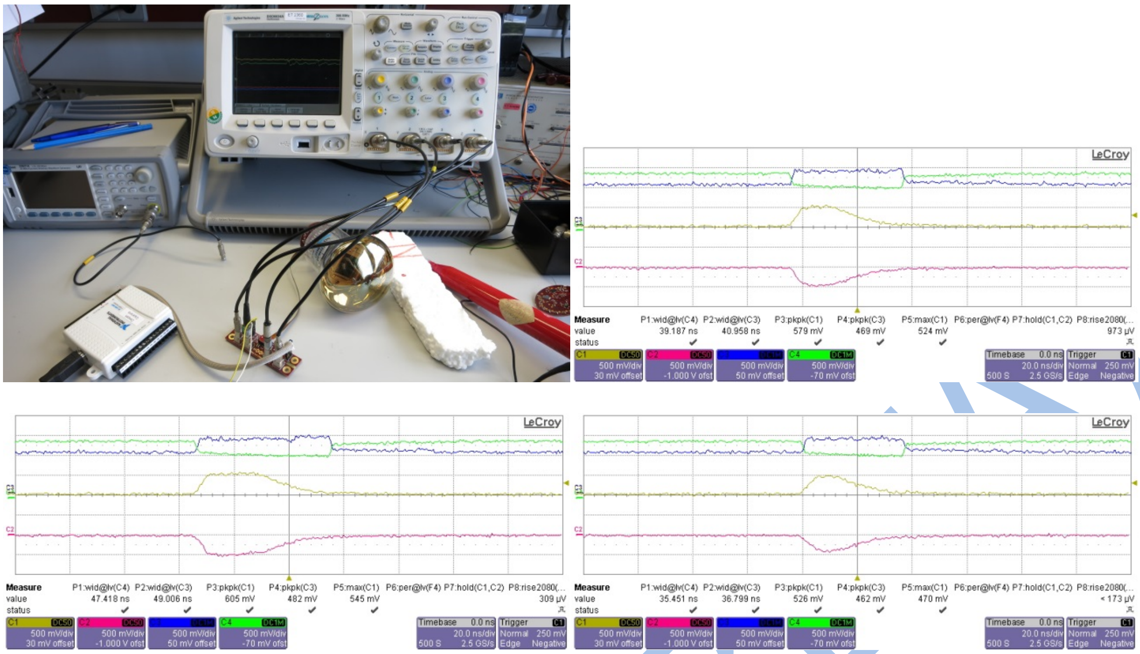


Figure 12 ToT measurents using LEMO cables, sample plots of LVDS signals and analog buffer signals when the PMT was put in the dark (for a gain of 5E6, threshold setting of 0x2B respectively).

References

[1] P Timmer et al, “Very low power, high voltage base for a Photo Multiplier Tube for the KM3NeT deep sea neutrino telescope”,TWEPP 2010, JINST 5 C12049 doi:10.1088/1748-0221/5/12/C12049

[2] D Gajanana et al, “A Front end ASIC for the readout of the PMT in the KM3NeT Detector” , TWEPP 2010, JINST 5 C12040 doi:10.1088/1748-0221/5/12/C12040

[3] D Gajanana et al, “ASIC Design in the KM3NeT Detector” , TWEPP 2012, 2013 JINST 8 C02030 doi:10.1088/1748-0221/8/02/C02030