Licel PM-HV

Gated Photomultiplier Module R9880U

Manual

June 9, 2022

Contents

1   Product description

The High Dynamic Range Photomultiplier from Licel has been specifically optimized to enhance the results of your measurements in pulsed applications. The compact design combines a stabilized dynode chain for strong light pulses with fast rise times and narrow pulse widths for high single photon count rates. This combination allows high dynamic range measurements by using both analog and photon counting measurements together, thus extending the linear dynamic range to 5 orders of magnitude.

Additional advantages are reduced space charge effects and higher light levels that can be measured without suffering from nonlinearities. These qualities make the Licel High Dynamic Range Photomultiplier your ideal detector for applications such as Lidar, fluorescence detection and other spectroscopic methods

1.1   Gating of the PMT

Gating of the photomultiplier can be used to reduce the amplification of the dynode chain temporarily. This is useful in applications where the dynamic range of the acquisition electronics would be exceeded or where the last dynodes would be overloaded.
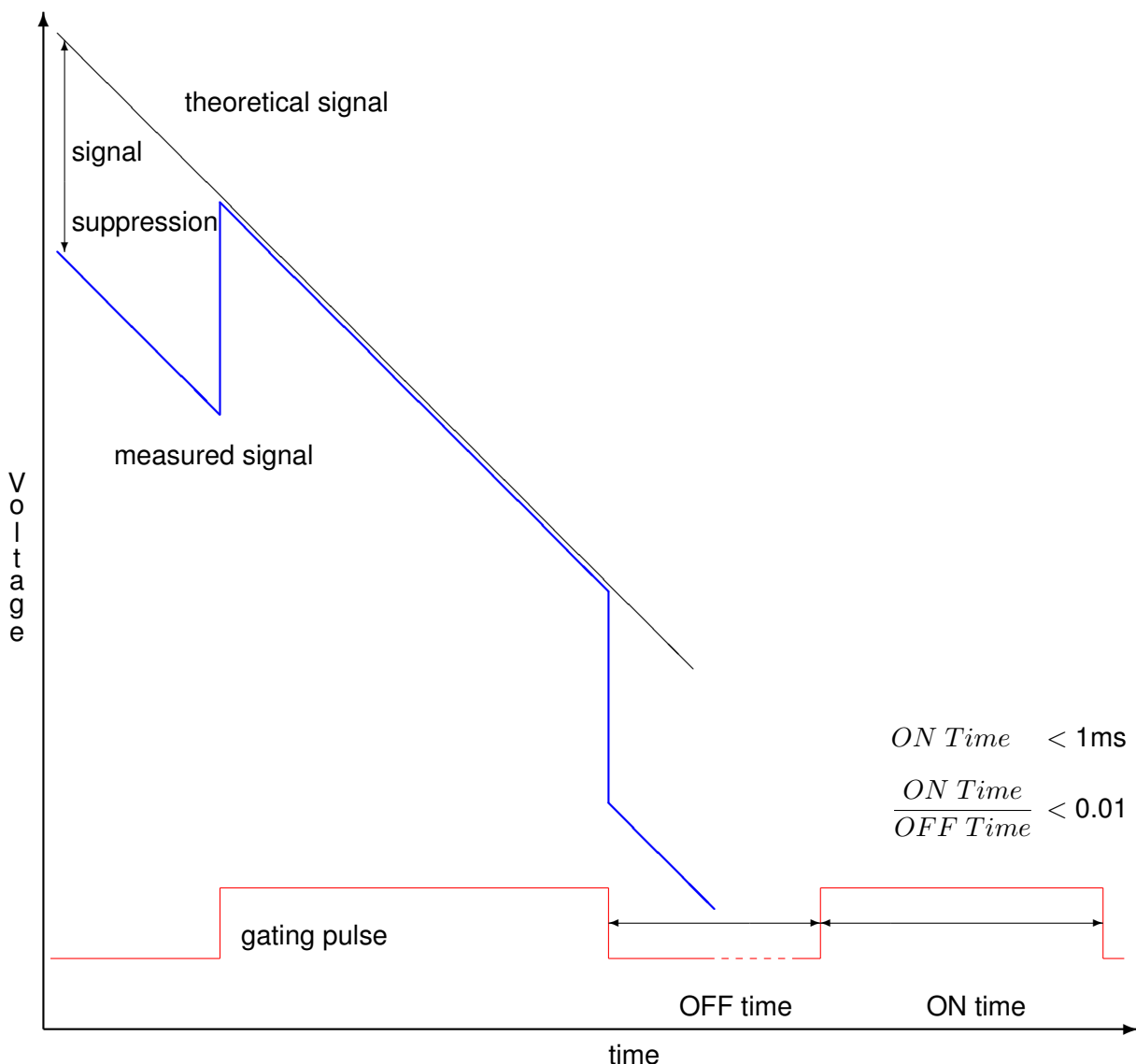
The gating in this tube is an active ON type. The amplification is reduced as long as the gating

pulse is kept LOW. The tube is operated with nominal gain as long as the gating pulse is HIGH (>2.5V).

The maximum ON time (nominal gain) is 1 ms. The maximum duty cycle (ON time/OFF time) is 1%.

The gating changes the amplification of the tube. If one has a PMT which is illuminated with a DC light level and the gating is turned ON. Then the settling time describes the required time to achieve the specified percentage of the final DC signal that would be achieved if the gating pulse is for a very long time on.

The reduced signal region should not be used for data retrieval as electronic interference will dominate in this region. The requirement for a positive gating signal is strict, if no gating pulse is supplied the tube will be always in the low sensitivity mode. A gated PMT module cannot be used in ungated (always ON) mode.

The use of the Licel Timing generator together with the gating is described in a companion manual http://www.licel.com/GatingTrigger.pdf. Other timing generators can be used for generating the gating pulse, the only requirement is that the generator can deliver more than 2.5V into 50Ω.

2   Handling of PMTs

It is recommended that photomultipliers are stored in the dark and are protected from excessive light also during installation. After illumination the dark current will be temporarily increased. Especially the red sensitive cathode type R7400-20 is sensitive and should be kept in dark also during the mounting procedure.

Do not store or use photomultipliers in a helium rich atmosphere. Helium will diffuse through the housing and destroy the internal vacuum.

3   Operation of PMTs

High voltages used in photomultipliers may present a shock hazard. The combination of high voltage and large capacitors can be fatal. When operating PMTs always make sure that the housing of both PMT and HV supply are properly grounded.

The high voltage setting must be in compliance with the average maximum anode current (100uA over 30 seconds for all R7400 or R9880U PMT's).

The high voltage setting should be set according to your signal strength and signal shape. If your peak signal amplitude is always below 20mV (into 50 Ω) the recommended HV setting is 1000V.

If your peak signal amplitude is higher, reduce the high voltage until the max. amplitude is not above 100mV for more than 50us or not above 500mV for more than 10 us. The specified gain reduction of 10E-3 is achieved when using high voltage settings between 800V and 1000V.

4   Pulse Height Distribution

When operating a PMT in photon counting mode the question is: Where to put the discriminator level? From the signal to noise ratio point of view the optimum will be a level where most of the noise counts are removed while only a minor part of the signal is lost. This point is called the valley point. The pulse height distribution can be shown using two modes:

Integral Mode: All counts below the specified the discriminator level are shown.

Differential Mode: Here the counts with a pulse height between the current and the adjacent discriminator level are shown.

In order to acquire a pulse height distribution set the PMT to a desired voltage and illuminate the PMT using a continuous light level. We have found, that a signal with a mean count rate of 2 MHz or 0.1 count per 50 nsec bin is just fine. A sky with scattered clouds is definitely not stable enough. A LED powered by a DC supply is preferred.

So before running the PHD software the corresponding light levels should be set up. As reference level we use a discriminator level of 10, which corresponds to -3.96 mV. A typical dark PMT will show only few counts or none at all after 1000 shots.

When the continuous light is applied the signal rises to 0.1 count per bin or 2MHz count rate at discriminator level 8 (-3.1mV).
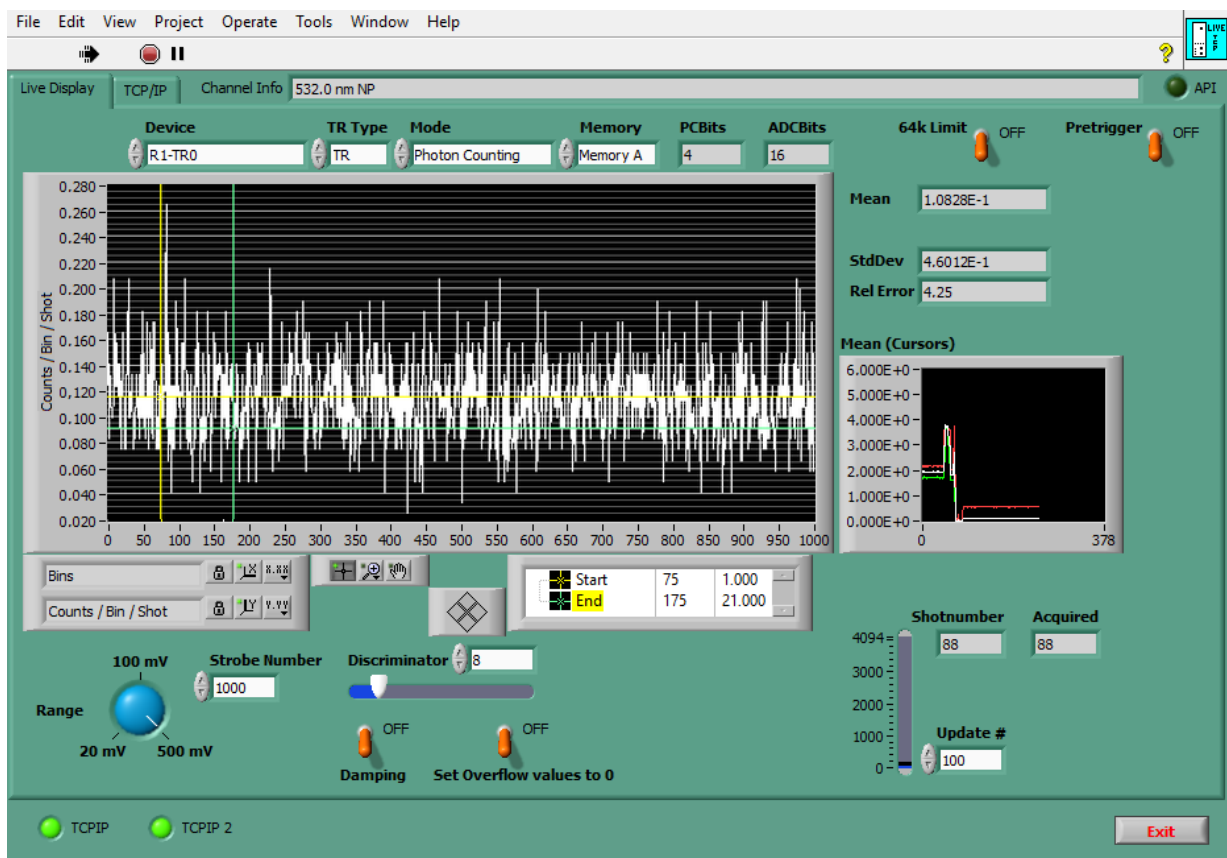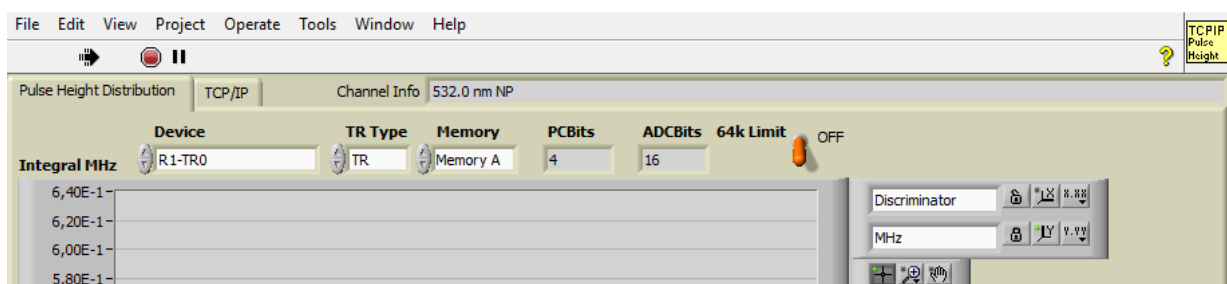

Use the `TCPIP Pulse Heigth Distribution.vi` from the `TCPIP-Pulse.llb` or the `TCPIP Pulse Height Distribution.exe` if you prefer the executable.
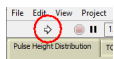
 The first step is to press the LabView typical `Run` button.

You should then select the transient recorder at the `Device` control and the transient recorder type (`TR-xx-xx` or `PR-xx-xx`)

While a shot number of 100 shots per discriminator level is fine for an integral pulse height distribution, you should select significantly more for a differential pulse height, for instance 4000 shots. Acquire 4000 * 63 shots to get the PHD. A typical pulse height measurement using a 30Hz laser as the trigger source would require 2.3h of total acqisition time. The TR 20-160 can run at 300Hz, which will cut the acquisition time down to 840 sec or 14min. Using a faster trigger source is therefore recommended. The illumination level must be kept constant over this period of time as it would otherwise distort the the PHD.

A typical sample of a integral PHD with 100 shots per discriminator level is shown below. Press the `Start` button to begin the data acquisition. The data display will be updated once the shots for a discriminator level are acquired.
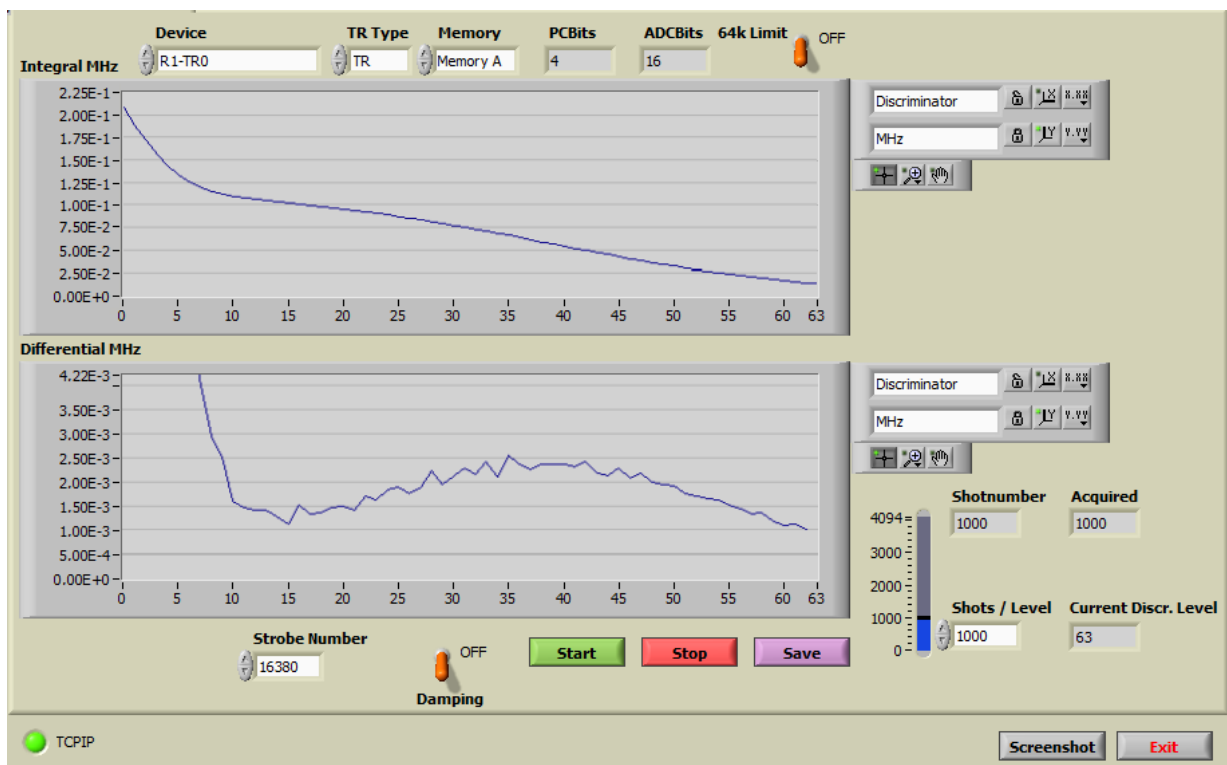
Please notice the change in the slope around discriminator level 10. The differential PHD for the same light intensity makes that more obvious. Select the differential field on the right side of the data display to get the differential PHD.

Here the valley point can be seen at discriminator level 10 which should then be used in the acquisition program. As the valley is not very sharp a discriminator level of 8 might also be a good choice.

If no clear valley point is visible but the differential PHD shows still a significant level at 63 then repeat the mesurement with the Damping switch in the ON position. This will give more complete coverage. The valley point then needs to be multiplied by 4 as the discriminator level is 4 times larger with damping on.

These values can then be used in the configuration data of the transient recorder in the acquisition program.

TCPIP Acquis Configuration   ✕

File

Configuration File Path
c:\Program Files (x86)\Licel\Licel TCPIP Acquisition\acquis.ini

Transient Recorder Setup | Global Measurement Configuration | Missing Trigger Behavior | Power Meters

Selected Transient Recorder
Rack 1 - Transient Recorder 0

☐ Use for all

		Bins	Data Reduction		Wavelengths	Polarizations	PM Voltages	Custom Info	Detector Assignment
✔ Squared Data	Analog Mem I ●	16380	0.00	Laser Mem I	355.00	Parallel	800.00		\<not assigned\> ▼
2000 Bins	Photon Mem I ●	16380	0.00	1	532.00	None	800.00		\<not assigned\> ▼
	Analog Mem II ○	8000	0.00	Laser Mem II	355.00	Parallel	850.00		\<not assigned\> ▼
	Photon Mem II ○	16380	0.00	1	355.00	Parallel	850.00		\<not assigned\> ▼
	Analog Mem III ○	16380	0.00	Laser Mem III	355.00	Parallel	850.00		\<not found\> ▼
	Photon Mem III ○	16380	0.00	By WL	532.00	None	800.00		PMT_0815 \<PMT 1\> ▼
	Analog Mem IV ○	16380	0.00	Laser Mem IV	532.00	None	800.00		PMT_0815 \<PMT 1\> ▼
	Photon Mem IV ○	16380	0.00	By WL	532.00	None	800.00		PMT_0815 \<PMT 1\> ▼

PC Bits	ADC Bits	Shot Limit	TR Type	Sampling Rate / MHz	Discr. Level	mV Range	Threshold
4	16	4k	TR	40.00	8	500 mV	Low

HWCAP: 00000079   binshift: 0.0   ID: 0709C0A8

Save and Exit   Exit without Saving

5 Using the PMT in a LIDAR

5.1 Maximum DC Signal

The maximum allowed average anode current for a R7400 or R9880 PMT is 100 μA. This corresponds to 5mV in the analog mode at a 50Ω input averaged over a 100 ms time. **This should never be exceeded**. The Licel PMT has a high current clamp down which will reduce the signal once more than 120 μA are drawn from the tube for more than 100...1000ms. If this happens the signal will be severely distorted and not useful for any LIDAR measurement. 5mV background signal can be easily reached during day time when the field stop is not small enough or the interference filters are too wide. Reducing the high voltage below 800V might help on first glance but is not optimal as a long term solution. The PMT cathode can provide a limited amount of photons over its lifetime, exposing the tube to a constant DC light will shorten this lifetime.

5.2 Peak Signal

The peak signal can significantly exceed the background level as long as the integral current is below 100 μA. The analog signal should fit into the input range of the preamplifier and the ADC. Due to the fluctuations of the lidar signal the following rule of thumb will keep the signal inside the ADC range.
    The peak signal should not exceed half of the input range.
For a 100mV input range this corresponds to 50mV.

5.3 Cathode structure

The cathode of the PMT has an inhomogenous sensitivity due to the dynode structure which will result in signal modulations if the signal spot changes its position on the cathode between then near and the far field signal. To avoid this the primary mirror should be imaged on the detector rather than the field stop.

5.4 Analog Measurements

For analog measurements a background profile is mandatory as otherwise ADC slopes or electro-magnetic interference will be taken as real atmosphere response.

5.5 Analog and Photon counting

The Licel transient recorder systems have a parallel analog and photon counting detection chain. The combination of both signals allows using the high linearity of the analog signal for strong signals and the high sensitivity of the photon counting for weak optical signals. The integration of both detection mechanism into a single device avoids ground loops and other problems that make the combination otherwise cumbersome. The main idea of the signal combination is that there is a region where both signals are valid and have a high signal to noise ratio. For typical Mini-PMT this region extends from 0.5 to 10 MHz in the photon counting.

To combine (glue) both signals, the photon counting needs a dead time correction.

5.5.1 Analog Detection

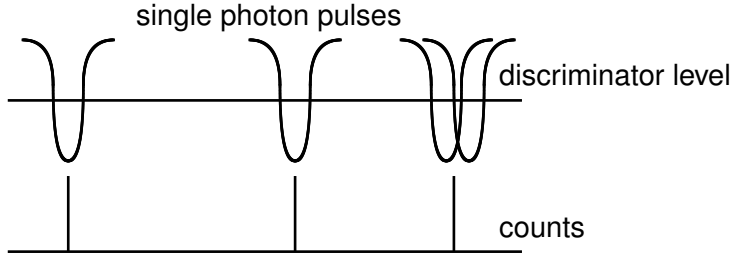single photon pulse

ADC input
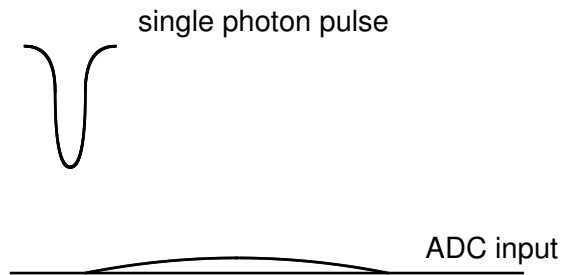
The single pulse from the PMT is passed through a anti-alias filter and then preamplified. The resulting signal is fed into an ADC. For a single pulse only a few ADC bits are used and the noise of the preamplifier and the ADC is comparable to the signal fed into the ADC. Under these conditions photon counting has a higher SNR.

single photon pulses

ADC input
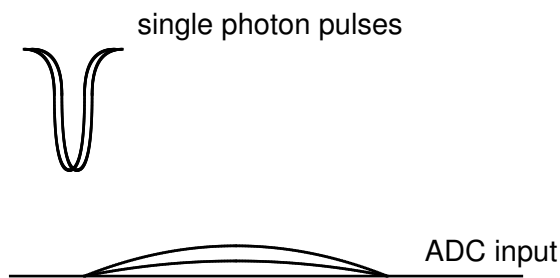
If two single pulses overlap the signal at the ADC will increase proportional. Due to this effect the ADC does not have a dead time constraint even for high count rates. For high count rates the linearity of the analog signal is superior to the photon counting.

5.5.2 Photon counting

Each single photon pulse is compared to a discriminator threshold. Signals that exceed the threshold cause a count. This is less sensitive to noise and baseline drifts. However due to the statistical nature of the pulses two of them may be so close together that they are not distinguishable at the discriminator and cause only a single count instead of two counts. This is described as the dead-time due to pulse pile up. As a consequence the observed count rate is less than the true incident count rate.

There are two typical dead-time scenarios, while the Licel photon counter can be best described as nonparalyzable. For a detailed discussion of the theory of photon counting dead time correction please see the excellent paper: *D. P. Donovan, J. A. Whiteway, and A. I. Carswell, "Correction for nonlinear photon-counting effects in lidar systems," Appl. Opt. 32, 6742-6753 (1993)*.

5.5.3 Paralyzable System

For a paralyzable system a single photon starts a dead time which can be extended by the next photon that arrives within the dead-time. For instance photon are 4ns wide and one photon follows 2ns and 5ns after the first one, the count will be 1 as the dead time starts again with the second photon.

$$N = S \exp(-S\tau_d) \tag{1}$$

Where:
N - is the observed count rate
S - is the true count rate
τ_d - is the system dead time

5.5.4 Nonparalyzable System

For a a paralyzable system a single photon starts a dead-time which will not be extended by the next photon that arrives within the dead-time. For instance photon are 4ns wide and one photon follows 2ns and 5ns after the first one, the count will be 2 as the second photon will be suppressed.

$$N = \frac{S}{1 + S * \tau_d} \tag{2}$$

N - is the observed count rate
S - is the true countries
τ_d - is the system dead time

While the paralyzable case is nonlinear equation, the nonparalyzable case can be easily inverted to

$$S = \frac{N}{1 - N * \tau_d} \tag{3}$$

As both cases are only a theoretical model, they are valid for lower count rates but fail when $S * \tau_d$ becomes larger than one. From a numerical point of view Eq. 3 can be only applied to a signal as long as

$$N < \tau_d \tag{4}$$

As an example the correction factor for a time constant of 4ns and a observed count rate of 5 MHz is 1.02. As typical averaged maximum observed count rate is 160MHz the correction factor would be 2.77. This would imply an maximum count rate of 470MHz. The glued profiles however show a virtual count rate in the 2GHz region for a 20mV peak.

5.6 Typical Dead Time Values

The observed dead times are always a combination of different dead times. The detector pulse width, as the discriminator level and the dead time of the photon counter itself influence the values. For the nominal values for the HV (850V) and a discriminator level of 8 at the Licel transient recorder (which is a good starting point for photon counting lidar setup) we found that 3.7ns or 270MHz is a good estimate.

5.7 Discriminator threshold and dead time values

When the discriminator threshold is lowered the observed count rate increases. There are two physical limits that work against this, if the threshold is very low, level 0 till 2 one will loose the advantages of photon counting and become vulnerable to electromagnetic noise. In extreme cases a continuous counting can be observed where the signal appears as inverted as the pulses corresponding to photons will elevate the voltage level over the electromagnetic noise and the observed count rate will drop.

For low discriminator levels it is possible that the same photon pulse is counted twice once as the normal peak and once for the ringing after the peak. The signal will be partly proportional to the incident light flux, however nonlinearities should be expected that are difficult to correct for. A typical test is to verify that a constant low light level produces counts that adhere to the Poisson statistic.

On the opposite side rising the discriminator level, will throw away a significant part of the small photons and reduce the observed dead time. The highest linear range will be achieved when half of all photon pulses are thrown away. This linearity comes at a high price, the dead time correction models do not work anymore and the system becomes more fragile as small changes in the discriminator and high voltage of the PMT will significantly influence the result. The method is known in the literature as a physical dead time correction.

A related issue is a hyper linear behavior if the discriminator threshold leads to large portions of the small counts to be thrown away. For low count rates this does not negatively influence the signal. However for medium strong signals the following will happen: two small photons that would be normally discriminated will form a countable photon if they overlap. They might compensate the loss in count rates for larger photons that overlap. This is the mechanism that is described above. However if they overcompensate, the observed count rate will exceed what should be a linear response. A typical observation of this behavior is that for glued profiles the pure photon counting exceeds the glued count rate over the gluing point.

A pulse height distribution where the pulses are all small and no valley point can be observed can lead to this behavior. If such a pulse height distribution is observed, there are two recommendations, first increase the high voltage, this will make the photons larger, second decrease the discriminator level. However the limitations that are outlined above also apply in this case.

6 Mechanical Dimensions
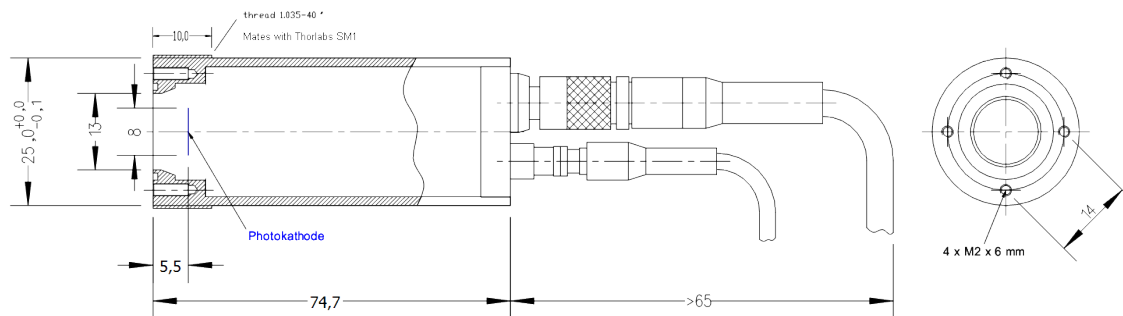
all dimensions in mm

7 Gated PMT - Cabling
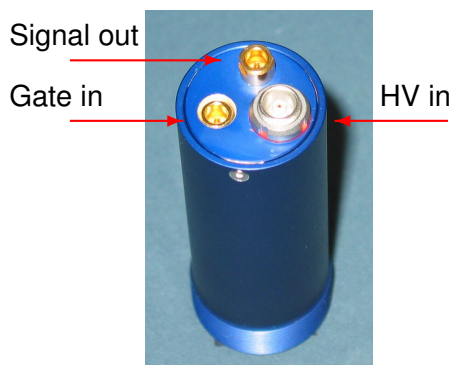
8   High Voltage Control Pinout

8.1   H11 connector on the rear side of the PMT-HV cassette

Pin	Description
2	+13...+15V in (max. 280mA)
5	Gnd
8	+5V Reference out
11	Gnd
14	Inhibit (high = off)
17	+12V Reference out
20	Gnd
23	Remote HV Control, 0..+1V into 100kOhm
26	Voltage Monitor (-5mV/V)
29	Current Monitor (2mA/V)
32	Protective Gnd (Case)

9 Specifications

Detector:

cathode diameter:	8 mm
spectral sensitivity	
Multialkali cathode-01:	310-850 nm
Multialkali cathode-20:	310-920nm
Multialkali cathode-04:	310-850 nm
SBA cathode -110 :	320-700 nm
SBA cathode -113 :	230-700 nm
UBA cathode:	310-700 nm
max. average anode current:	0.1 mA
gain:	10^5-10^6

Signal specs:

single photon rise time:	$<$1.3 ns
single photon width (FWHM):	$<$2.2 ns
pulse load stability, HV=850V, 100mV signal / 60μs	$<$0.15%

Gating:

Active ON type	
Gate Pulse Input:	$>$2.5V into 50Ω
Suppression, Gate OFF:	$<10^{-3}$
Rise time:	$<$10 ns
Settling time:	(99%) $<$200 ns
Settling time:	(99.9%) $<$5 μs
Max. ON time:	1 ms
Max. duty cyle (ON/OFF):	0.01
Switching noise:	$<$10mV for $<$200 ns
High voltage range:	750-850V

HV supply:

voltage range:	-100...-1kV
max. current:	2 mA
voltage ripple:	$<$1 mV (DC to 20 MHz)
remote control voltage:	0..+1V
Mechanics:	
PMT module size:	70 x 25mm
PMT module weight:	50 g
Optical interface:	O-ring sealed mount or adapter for 1" Thorlabs lens tube system
High voltage supply:	50.5x128.4x103mm 3 height units, 10 width units standard cassette

Connectors:

Gating in: Minax/BNC 2m
Signal out: Minax/BNC 2m
HV to PMT: Lemo Camac 2m
HV power supply: H11 connector
Power supply: 15V DC, 250mA

Environmental conditions:

Operating temperature: 0°C to 30°C (non condensing)
Storage temperature: -40°C to 70°C

System integration:
Mating parts of Thorlabs Lens tube system SM1L03, SM1L05,...1" stackable lens tubes
SM1NT Locking Nut and other components of the SM1 series