InGaAs Single-Photon Detection Module *"Gated"*

MICRO PHOTON DEVICES

InGaAs Single-Photon Detection Module

Via Stradivari, 4 • Stradivari Strasse, 4
39100 Bolzano - Bozen, BZ • Italy
Phone +39 0471 051212 • Fax +39 0471 501524

Table of Contents

Chapter 1

1 Getting Started

This chapter provides the introduction on the MPD InGaAs Single-Photon Detection Module that will help you get acquainted with the product. It also includes the installation and configuration procedures that will support you in getting started with the system.

1.1 Introduction

The InGaAs single-photon detection module is built around a Peltier cooled InGaAs/InP Single-Photon Avalanche Diode (SPAD) for the detection of near-infrared single photons from 900 nm up to 1700 nm.

The module includes a programmable frequency and pulse generator for gating the detector, a front-end circuit for photodetector's avalanche sensing, a fast circuit for detector's avalanche current quenching and operative bias voltage resetting and some sub-circuits for signal conditioning. All the main parameters are adjustable by the user through the software interface, in order to match the requirements of the different applications.

The system is composed by two parts:

- A Detection Head which comprises of a InGaAs/InP SPAD detector and the related fast electronics. Its small dimension allows its easy integration in all experimental setups. The detection head can be of two types: *Gated-mode* or *Free-running*.

- A Control Unit which contains the pulse generator, the Peltier controller, the communication system and the power supplies of the entire module. The control unit is the same for both types of detection heads.

They are connected together through a 2 m long wide-bandwidth cable.

The system can be conveniently used both for counting and timing measurements, since the high performance electronics guarantees a clean temporal response even with fast gate transitions.

1.2 The photon detection module

1.2.1 Standard module configuration

A standard InGaAs Single-Photon Detection Module is usually shipped with these parts:

- Control Unit;
- Detection Head (either with a fiber-pigtailed SPAD or with the detector placed behind a standard glass optical window) ;
- Orange wide-bandwidth Cable for Control Unit to Detection Head connection;
- MPD universal optical table adaptor for Detection Head mounting (optional);
- Power cord;
- USB key containing the installation software and the user manual in PDF® format;
- A SPAD test report.

Figure 1.1. A standard configuration for the InGaAs/InP single photon detection module.

1.2.2 Preparation for use and care.

Before using and powering-on the module the following precautions must be followed:

1. The InGaAs Single-Photon Detection Module, MUST be unpacked and set-up as reported in paragraph 3.1.1.

2. NEVER switch-off the module if the SPAD has not being turned off by the control software as explained in paragraph 3.1.4

3. Avoid switching on the module if the orange wide-bandwidth cable has not been properly connected to both the Control Unit and the Detection Head.

4. Never un-connect the orange wide-bandwidth cable if the module is powered-on.

5. In order to use the module, the controller software has to be installed on a PC, following the instructions in paragraph 2.1.

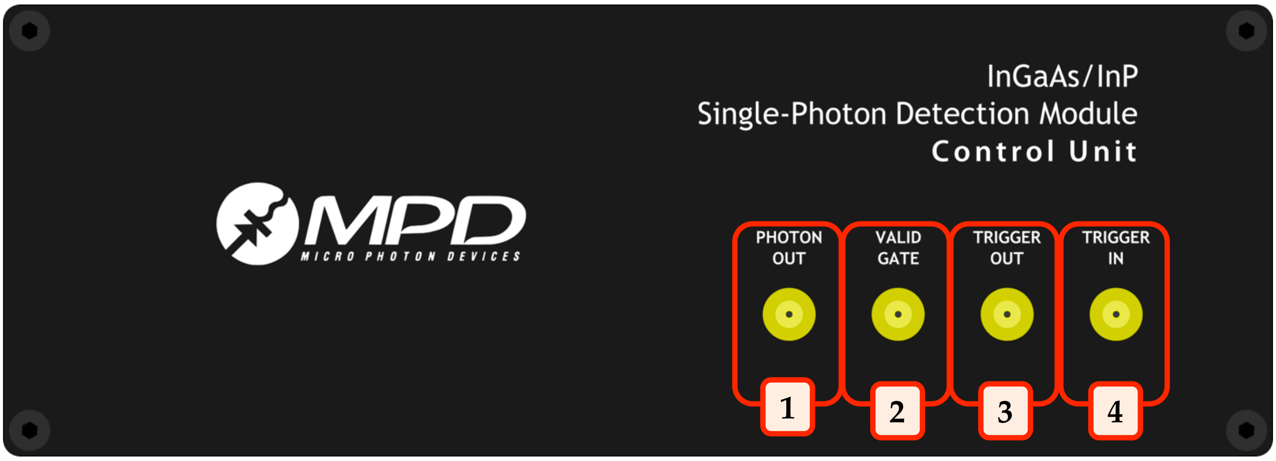
6. Before connecting any cable to the front panel connectors make sure that signals are compatible with the levels specified in Chapter 4. Also pay attention on signals polarity and invert them if necessary.

1.2.3 Care of the SPAD optical interfaces

Please follow these instructions for fiber care:
1. avoid any unnecessary force that may cause the fiber to bend sharply and break;
2. bare fiber should not support the weight of the connector;
3. cap end face when connector is not in use;
4. inspect the end face of the fiber for dust or imperfections with a fiber microscope;
5. clean any dirt from the end face with a lint-free wipe.

Please follow these instructions for the cleaning the window optical interface of your detection head:
1. Dust and other loose contaminants usually should be blown off before any other cleaning technique is employed. A canister of inert dusting gas or a blower bulb is needed for this method;
2. Do not use your mouth to blow on the surface because it is likely that droplets of saliva will be deposited on the optical surface.
3. If blowing off the surface of the optic is not sufficient, other cleaning methods and materials are acceptable. When cleaning an optic, always use clean wipes and optical grade solvents to prevent damage from contaminants. Wipes should always be moist with an acceptable solvent and never used dry. Acceptable wipes are pure cotton, lens tissue;
4. Typical solvents employed during cleaning are distilled water and isopropyl alcohol. Use all solvents with caution since most are poisonous, flammable, or both. Read product data sheets and MSDS sheets carefully before using any solvents;
5. If repeated cleaning is required it is recommended the use of distilled water to be used more frequently than the cleaning fluid and to apply the smallest amount of pressure when wiping the surface with lens tissue paper;

1.3 The Control Unit's Front Panel



The control unit is the same independently on the type of the Detection Head (free running or gated).

1. PHOTON OUT : *output*, SMA connector;
   a digital pulse is generated for each detected photon; the output is a NIM pulse, which means that it must be 50Ω terminated and that the low logic level is 0 V and the high logic level is -800 mV. The falling edge of the pulse marks, with very low jitter, the photon arrival time;

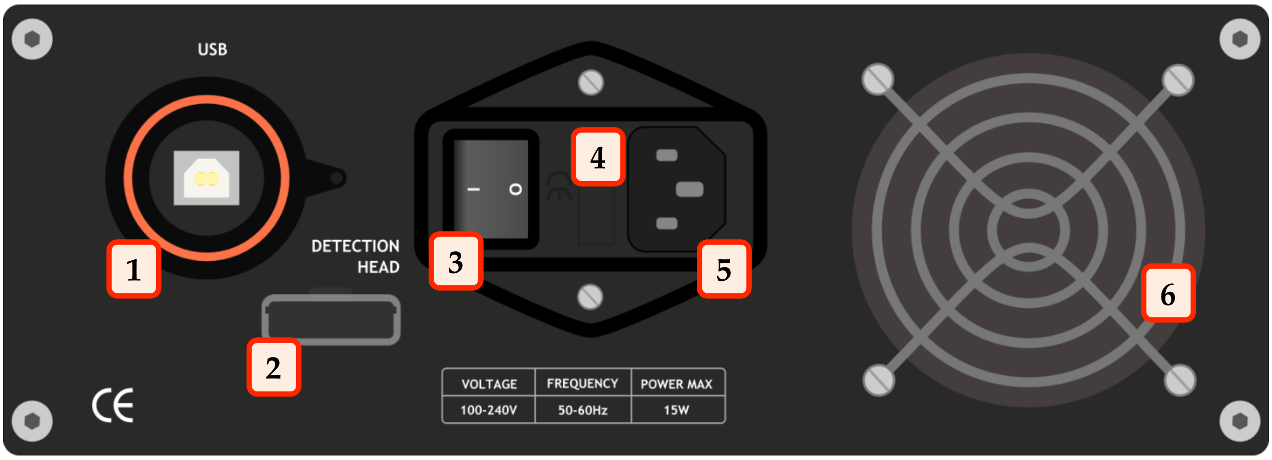
2. VALID GATE : *output*, SMA connector;
   outputs which *Gate* pulses effectively enabled the SPAD (non-masked gate pulses). The pulses are LVTTL standard. See paragraph 1.5 for a detailed description of the VALID GATE signal;

3. TRIGGER OUT : *output*, SMA connector;
   outputs the internal trigger reference signal used to periodically enable the SPAD. Normally disabled, it is enabled only when *internal trigger* is selected from the user interface. The pulses are LVTTL standard;

4. TRIGGER IN : *input*, SMA connector;
   if an external trigger is needed, then the signal must be connected to this input. The external trigger signal can be positive or negative within the range from -2 V to +2.5 V and the internal comparator allows for a programmable threshold.

For a complete understanding of the module input and outputs and their absolute maximum ratings please refer to Chapter 4.

1.4 The Control Unit's Rear Panel



1. USB Connector : holds the USB type-B cable for PC connection;
2. Detection Head cable connector : holds the wide-bandwidth cable for Detection Head and Control Unit connection;
3. Power Switch : used to switch on and off the module;
4. Fuse Holder : contains the 1 A fuse, to protect this appliance;
5. Power Inlet : holds the power cord to supply the unit;
6. Fan opening : permits the air to recirculate into the unit.

Note

Be careful during the module power off sequence: ALWAYS remember to turn off the detector using the control software as described in paragraph 2.4.1 before switching off the module using the Power Switch. **Incorrect shutdown procedure can irreparably damage the SPAD detector.**

1.5 The InGaAs/InP Single-Photon Avalanche Diode

The core of this module is a Single-Photon Avalanche Diode (SPAD), housed into the Detection Head. The detector has a 25 μm diameter active area and it is mounted on the top of a three-stage Peltier cooler. A SPAD is a p-n junction, biased well above the breakdown voltage (VB), that stays in a meta-stable state with no current flowing. At this bias, the electric field is so high that a single charge carrier injected in the depletion layer can trigger a self-sustaining avalanche [1]. The current rises swiftly (nanoseconds or sub nanosecond rise-time) to a macroscopic steady level, in the milliAmpere range. If the primary carrier is photo-generated, the leading edge of the avalanche pulse marks the photon arrival time. The current continues to flow until the avalanche is quenched by lowering the bias voltage down to or below VB. Then the bias voltage must be restored, in order to detect another photon. These operations are usually performed by a suitable circuit named Active Quenching Circuit (AQC) [2].

The device primary source of internal noise consists in a random dark-counting rate (DCR) arising from free carriers thermally generated. These events compete with photons in triggering the detector and thus impair the signal to noise ratio [3]. The Peltier cooler is therefore useful to lower the temperature of the detector in order to diminish this effect.

Normally single photon detectors are operated in the so-called free-running mode, where the devices is enabled immediately after the quenching of each avalanche current. Normally this is true for Silicon SPADs but for InGaAs SPADs the DCR would be so high that the use of these detectors would be almost impossible. As a consequence, for further reducing these unwanted counts, the InGaAs SPADs are operated in gated regime: the detector is periodically enabled for a short time window called *Gate*, of duration T_{ON} (*Gate Width*), whereas it is usually held off at a bias slightly below the breakdown voltage.

The counting rate (CR) of a detector operated in free running, and not in gated mode, is simply the number of counts generated by the module output (PHOTON OUT) divided by the integration time :

$$CR = \frac{Number\ of\ Counts}{Integration\ Time}$$

When the detector is operated in gated mode, the photon-out count rate (CR) must be corrected taking into account both the *Gate Frequency*, i.e. the frequency at which the SPAD is periodically enabled, and the *Gate Width* (T_{ON}), i.e. the time length during which the SPAD is turned on during each duty cycle. The correction is due to the fact that photons (or dark-counts) may be absorbed during the times the SPAD is kept turned off and so are not counted. The correction takes into account how many photons have been counted and for how long, during the integration time, the SPAD has been kept really turned on. In order to calculate the true counting rate, thus, the following formula must be used [4]:

$$CR_{DUTY} = -\frac{1}{T_{ON}} \log\ (1 - CR \cdot T)$$

where T is the *Gate Period*, i.e. the reciprocal of the *Gate Frequency*.

In most of the applications, this formula can usually be approximated to:

$$CR_{DUTY} \cong CR \cdot \frac{T}{T_{ON}} \quad for \quad CR \cdot T \ll 1$$

that is the raw counts divided by the duty-cycle applied to the detector.

However a secondary source of noise exists in SPADs: the afterpulsing. During the avalanche some carriers are captured by deep levels in the junction depletion layer and subsequently released with a statistically fluctuating delay. Released carriers can retrigger the avalanche, generating afterpulses correlated with a previous avalanche pulse which sum up with the DCR. In order to mitigate these avalanche re-triggerings, after each avalanche, during the subsequent gating occurrences, the detector is kept off for a user programmable time, named hold-off time, T_{HO}. In this way the trapped carriers can be released without triggering further avalanches. The hold-off time is particularly useful when cooling the detector since the afterpulsing effect worsens at low temperatures because the decay times of the trapped carriers increase. The hold-off time is always longer than the gate period T.

An example, of how a photon counter module, operated in gated mode and employing the hold-off feature, works, is shown in Figure 1.2. The reference signal is the *Gate Sync* which sets the gate repetition rate (frequency) and whose ON time corresponds to the T_{ON} of the SPAD. The *Gate* instead is the actual signal applied to the SPAD. Initially the *Gate* and the *Gate Sync* are the same. When a photon is absorbed, it triggers the avalanche current which is marked, in this example, by the raising edge of Photon Output pulse. Once the avalanche is detected it is immediately quenched; the system does not wait for the end of the Gate window to bias below breakdown the SPAD. Now *Gate* and *Gate Sync* begin to differ. Let suppose for sake of clarity that the hold off time is long about 2T (twice the gate period): during the hold-off time, the *Gate Sync* pulses are ignored, and the *Gate* remains low, keeping the photodetector OFF. The SPAD is enabled again only at the first rising edge of the *Gate Sync* signal after the end of the hold-off. The MPD InGaAs/InP module, in fact, allows to keep the detector OFF during a T_{ON} started before the end of the hold-off, so that the user does not risk to lose useful information contained in the first part of the ON periods.

Now, because of the hold-off time, the measured counting rate CR is not equivalent to the actual rate of photons but can be estimated by:

$$CR_{HO} = \frac{CR}{1 - CR \cdot T_{HO}}$$

In counting applications, the maximum count rate should be then limited at about $1/(2T_{HO})$, because for higher values the correction factor becomes so high that even small errors in the equation's parameters will result in high errors in the CR_{HO} counting-rate.

Since the MPD InGaAs/InP single photon counter biases the SPAD in gated mode and applies the hold-off every time an avalanche is detected, the two effects must be applied at the same time in order to obtain the correct photon counting rate CR_{photon} from the measured counting rate CR. From simple mathematics, it turns out that the final equation is the following:

$$CR_{photon} = -\frac{1}{T_{ON}} \log\left(1 - \frac{CR}{1 - CR \cdot T_{HO}} \cdot T\right)$$

which can then be simplified to :

$$CR_{photon} \cong \frac{CR}{1 - CR \cdot T_{HO}} \cdot \frac{T}{T_{ON}} \quad for \quad \frac{CR \cdot T}{1 - CR \cdot T_{HO}} \ll 1$$

Please note that the previous equations do not take into account the Photon Detection Efficiency of the InGaAs module. These formulas also strictly apply when the photon rate is uniformly distributed over time. Particular care must be used when applied to specific cases like the one discussed in paragraph 3.2.2.

Figure 1.2 is, in addition, very helpful in explaining the VALID GATE output. This signal is generated in order to properly trace which *Gate Sync* pulse effectively enabled the SPAD, i.e., which are the pulses that were not blanked during the hold-off time (VALID GATE has the same pattern of Gate, shown in Figure 1.2). This information is particularly useful when looking for the percentage of counts over the total number of available valid gates. In fact in timing measurements one must be careful not to exceed the single-photon statistics, in order not to distort the TCSPC histogram (see paragraph 3.2.2).

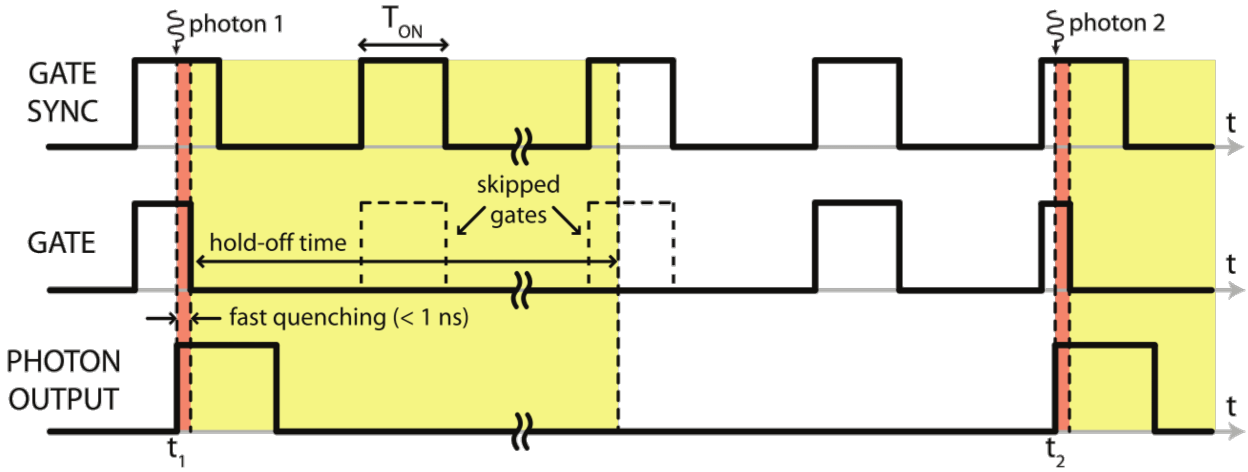


Figure 1.2. Main waveform in the module: output of pulse generator (GATE SYNC), pulses at the SPAD detector (GATE) and photon output signal (PHOTON OUTPUT).

1.6 Bibliography

- SPADs and quenching circuits:

[1] Cova, S., Ghioni, M., Lacaita, A. L., Samori, C., and Zappa, F. "Avalanche photodiodes and quenching circuits for single-photon detection", Applied Optics, 35(12), 1956—1976 (1996). http://dx.doi.org/10.1364/AO.35.001956

[2] Cova, S., Ghioni, M., Zappa, F., Rech, I., and Gulinatti, A., "A view on progress of silicon single-photon avalanche diodes and quenching circuits", Proceedings of SPIE , 6372, pp. 63720I-1 - 63720I-12 (2006). http://dx.doi.org/10.1117/12.685963

- InGaAs/InP SPADs:

[3] Alberto Tosi, Alberto Dalla Mora, Franco Zappa and Sergio Cova, "Single-photon avalanche diodes for the near-infrared range: detector and circuit issues," Journal of Modern Optics, 56:2-3, 299-308 (2008) - http://dx.doi.org/10.1080/09500340802263075

[4] Alberto Tosi, Alberto Dalla Mora, Simone Tisa, Fabio Acerbi, Franco Zappa and Sergio Cova , "InGaAs/InP SPADs for near-infrared applications: device operating conditions and dedicated electronics," Proc. SPIE 7681, Advanced Photon Counting Techniques IV, 76810R (April 28, 2010); http://dx.doi.org/10.1117/12.850696

- Paper on the InGaAs Single-Photon Detection Module:

[5] Alberto Tosi, Adriano Della Frera, Andrea Bahgat Shehata, and Carmelo Scarcella, "Fully programmable single-photon detection module for InGaAs/InP single-photon avalanche diodes with clean and sub-nanosecond gating transitions," Rev. Sci. Instrum. 83, 013104 (2012) - http://dx.doi.org/10.1063/1.3675579

Chapter

2

2 The Control Software

This is the operator's reference chapter which contains information about for the software front-panel of the InGaAs Single-Photon Detection Module.

2.1 Software Installation and Startup

Complete the following steps to install the controlling software for Windows®:

- Log in as system administrator or as a user with administration privileges.
- Disable any automatic virus detection programs before you install. Some virus detection programs could interfere with installation.
- Insert the USB key and copy the Install_for_Windows folder in a temporary location (for example your Desktop)
- Double click on the file named setup.exe located inside the folder you just copied.
- Follow the instructions on the screen until the installer ends.
- Connect the module at the PC, with the procedure detailed in Chapter 3.1.1.
- Windows® will automatically recognize the device and install the correct drivers. If a "found new hardware" window appears, select the option to automatically download recommended drivers from internet. For this reason, the computer on which the drivers will be installed, MUST BE CONNECTED to the internet. The drivers will create a virtual serial COM associated with the InGaAs/InP single photon counter.
- Once completed, you can start the controlling software from Windows Start Menu → Programs → MPD → InGaAs Single Photon Detection Module.
- Remove the temporary install folder.

2.2 Start Tab

When the software is started for the first time, the window illustrated in Figure 2.1 is shown. This window will have two tabs the *Start* tab and the *Summary* tab. With the *Start* tab, it is possible to detect and name all the InGaAs Single-Photon Detection Modules attached to the PC where the controlling software runs. It consists of a *Detected Modules* table and two buttons: *Autodetect* and *Accept Config*. The Start tab has also a menu bar, which is always present and does not change independently on which tab is currently selected. This menu bar has three menus: *File*, *Settings* and *Help*.

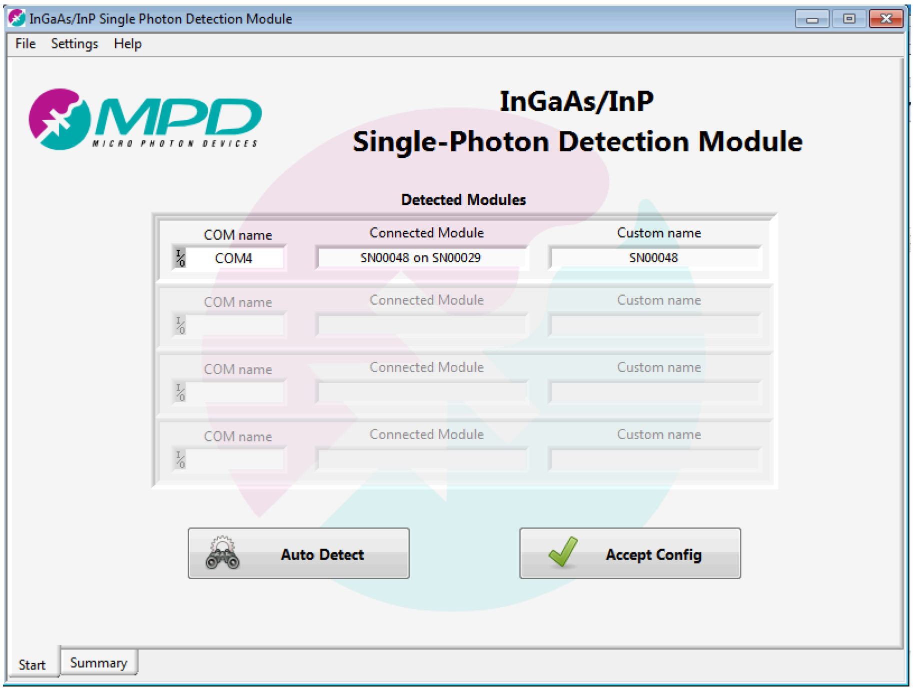


Figure 2.1. Start tab screenshot with one detected module.

2.2.1 Detected Modules table

In this table are reported all the detected modules. For each one the software displays the Detection Head and Control Unit Serial Numbers and, in order to simplify the system identification, a custom name can be assigned. By default the Custom Name corresponds to the Detection Head's serial number and is linked to the Detection Head and saved in the PC, so it is recalled every time this specific Detection Head is connected to the PC. This is true even if the Detection Head is connected through a different Control Unit. Of course any name can be chosen as Custom Name.

If the software has detected all the connected modules and the user has associated all the custom names, the *Accept Config* button can be clicked on. By accepting the configuration, the software will create additional tabs, one for each detected module as is shown in Figure 2.2.

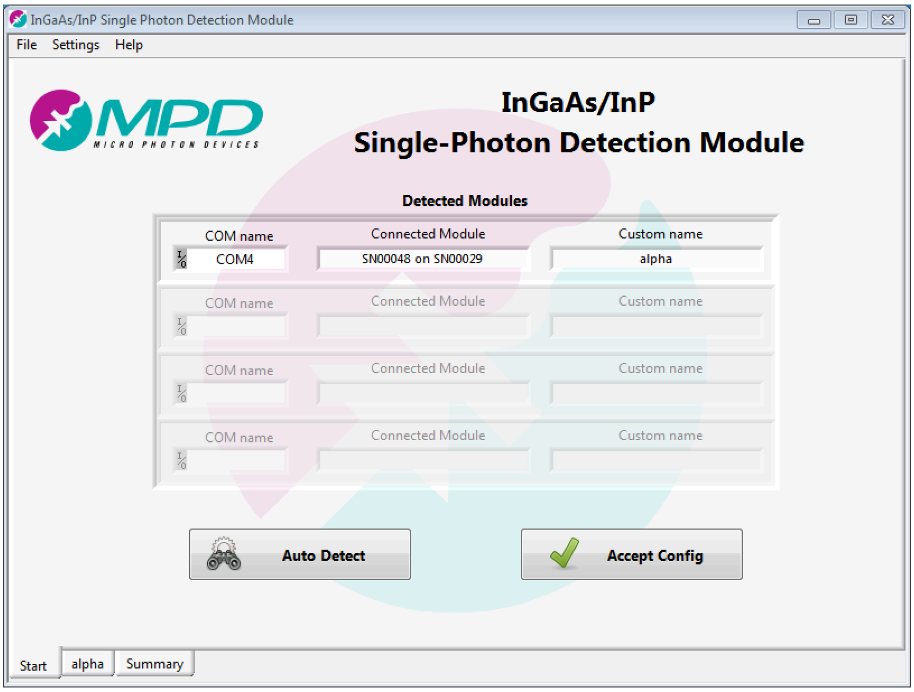


Figure 2.2. Start Tab screenshot after module renaming and "Accept Config" button pressed.

Each tab will allow the user the full control of the associated photon counter as will be shown in paragraph 2.4.

This table is automatically populated at each software startup with actual connected modules, unless the user has disabled the automatically search feature in the options panel as will be explained in paragraph 2.3. If other modules are connected to the PC without first closing the program, it is necessary to manually press the *Auto Detect* button as explained in the following section.

2.2.2 Auto Detect button

Pushing this button the software scans each COM port available on the system and sees if there is any attached module; then the *Detected Modules* table is updated according to the current scan. This function is automatically run when the program starts, unless a static COM number is assigned in the *Settings->COM Ports* configuration window.

2.2.3 Accept Config button

By pressing this button, the custom names, that have been assigned to the connected modules, are confirmed and the program populates the tabs with one page for each recognized system. Tabs report the *Custom Name* that has been given to each module.

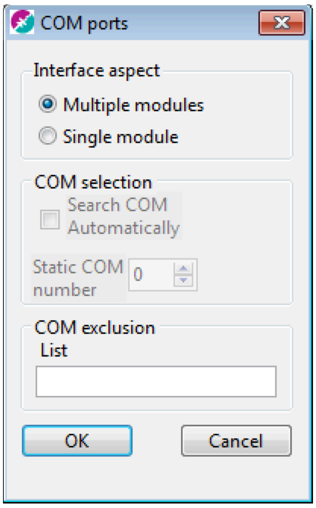


Figure 2.3. *COM ports configuration window.*

2.3 Menu Bar

The menu bar has three menus: *File*, *Settings* and *Help*. The *File* menu has only one item Exit and is used to exit immediately the program when the SPAD is turned off.

By pressing the *Settings* menu two items are shown : *COM ports* and *Advanced*. By pressing the first item of the list a configuration window (shown in Figure 2.3) will appear. Inside this window there are the following controls:

- *Interface aspect* radio button: it lets you to switch between *multiple* or *single module interface*. Using this last option, tabs are not shown and only one module can be managed. This option is very useful when only one photon counter has been attached to a single PC.
- *Search COM automatically* checkbox: in *Multiple modules* interface mode always enabled. This option can be set as desired only if the software has been set in *Single module* interface mode. If disabled, it does not force the program, during the start-up, to find automatically the right COM port where a module is connected. This option is very useful when the PC handles other serial instruments that do not like the CS# command, sent by the program in order to detect connected modules.
- *Static COM number* control: when the auto-detect checkbox is disabled, the COM port, to which the photon counter has been connected, must be specified in this field.
- *COM Exclusion List*: it lists the COM port numbers that have to be excluded from the automatic detection process. Use comma as number separator.

Note

You have to restart the program in order to make the changes active.

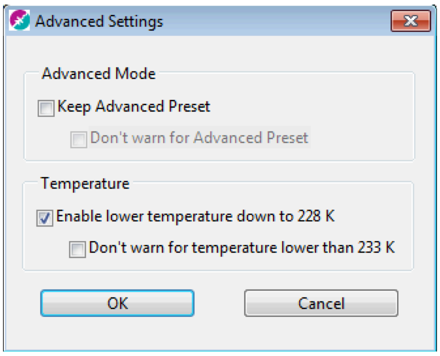


Figure 2.4. Advanced settings.

By pressing the second item of the *Settings* menu a configuration window (shown in Figure 2.4) will appear. Inside this window there are the following controls:

- *Keep Advanced Preset*: when selected, the program retains the last Advanced Preset settings also when you temporary switch on other presets. Otherwise these settings are overridden.
- *Don't warn for Advanced Preset*: deactivates the warning message when you switch to or you load an Advanced Preset.
- *Enable lower temperature down to 228 K:* allows to set, as SPAD temperatures, values below 233 K but higher than 228 K. The use of the detector at such low temperatures is advised only for overvoltages equal to or lower than 5V, moderate count rates and when the detection head is mounted on a very good heat sink. In case the detection head cannot reliably keep such low temperature it will shut down itself with a warning. In this case it is advised either to use temperatures higher than 233 K or to improve the module heat dissipation.
- *Don't warn for temperatures lower than 233 K*: deactivates the warning message when you operate the SPAD at temperatures lower than 233 K.
- If you have a DH with serial number equal to 49, 46, 42, 38, 37, 34, 33, 7, 4, 3, 1, the minimum achievable temperature is 230 K, it is already set by default and the actual standard or advanced temperature settings are ignored.

By pressing *Help*, on the menu bar, the menu shown in Figure 2.5 will appear.

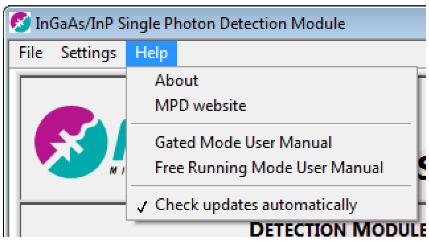


Figure 2.5. Help menu.

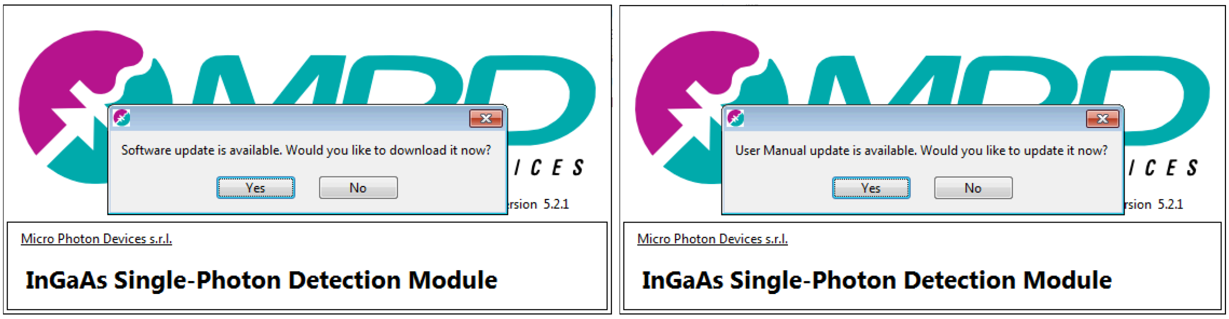


Figure 2.6. Software Update (left) and User Manual update (right) dialogue boxes.

The *Help* menu lists the following items:

- *About*: when pressed a dialogue box showing the program name, version and copyright will appear.
- *MPD website*: when pressed, the default web browser will open on the MPD webpage.
- *Gated Mode User Manual*: when pressed the default PDF reader will be opened and the InGaAs user manual, for the Gated mode module version, will be shown.
- *Free running Mode User Manual*: when pressed the default PDF reader will be opened and the InGaAs user manual, for the free-running mode module version, will be shown.
- *Check Updates automatically*: when this item is "ticked", on start-up, the InGaAs control software will look for software or user manual updates on the MPD website.
  - In case a new user manual is present, the dialogue box shown in Figure 2.6 on the right will appear and if the user presses the 'Yes' button the new user manual is downloaded and copied inside the program. A dialogue box signaling the successful install of the new manual will also be shown as illustrated in Figure 2.7.
  - In case a new software is available, the dialogue box shown in Figure 2.6 on the left will appear. If the 'Yes' button is pressed, the default web browser will be opened directly on the download page of the MPD website.

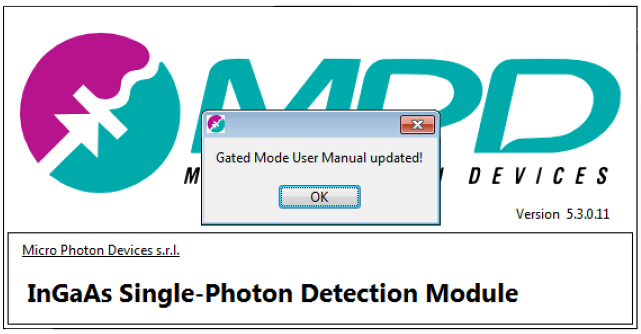


Figure 2.7. Dialogue box informing that the Gated-Mode User-Manual has been downloaded.

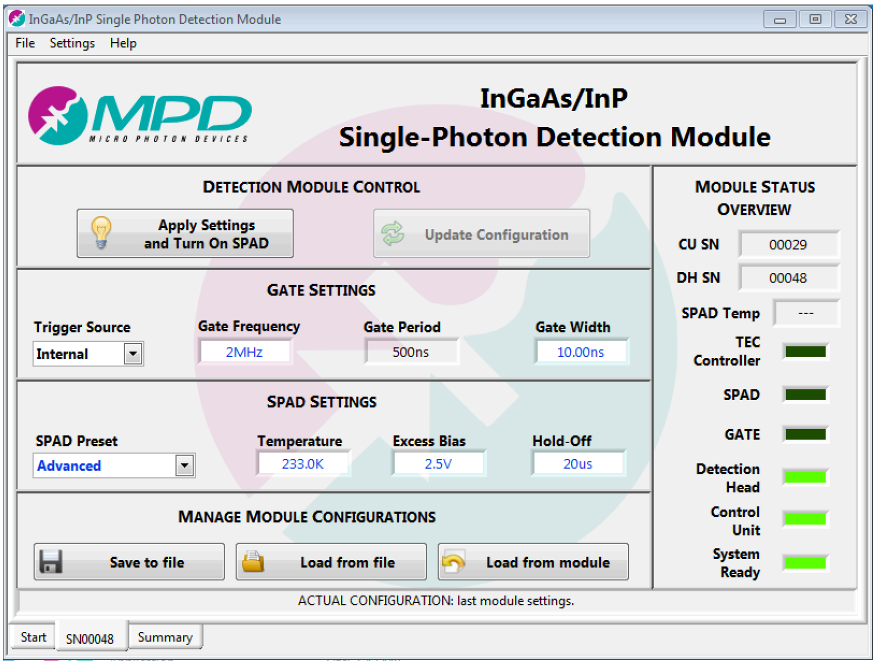


Figure 2.8. Module tab screenshot before turning on the SPAD.

2.4 Module Tab

After clicking the *Accept Config* button, in the *Start* tab, the software creates a module tab for each attached system. The tab label reflects the *Custom Name* given at the specific module. Every module tab opens an interface whereby all the configurable parameters of the detector, the trigger and the gate signals, can be set. In Figure 2.8 it is reported a page screenshot, taken before turning ON the SPAD. The next paragraphs will describe all the controls, buttons and indicators that can be found into this window, divided by section.

2.4.1 Detection Module Control

In this section of the panel there are two buttons: "*Apply Settings and Turn On SPAD*" and "*Update Configuration*" (Figure 2.8). The first button changes to "*Turn Off the SPAD*" after the InGaAs/InP SPAD has been turned on, as shown in Figure 2.9, and will revert to the first name after the turning off of the SPAD. The two buttons are used to upload the user-defined parameters in the control unit and turn on and off the detector. In particular:

- *Apply Settings and Turn On SPAD* button: if the detector is off, you can select a SPAD preset (i.e. the operating temperature, excess bias and hold-off of the photodetector) from the *SPAD Preset* drop box menu, and set the trigger and the gate parameters as described in next paragraphs. Completed this task, by pressing this button, all the settings are sent to the module and the detector turns on.

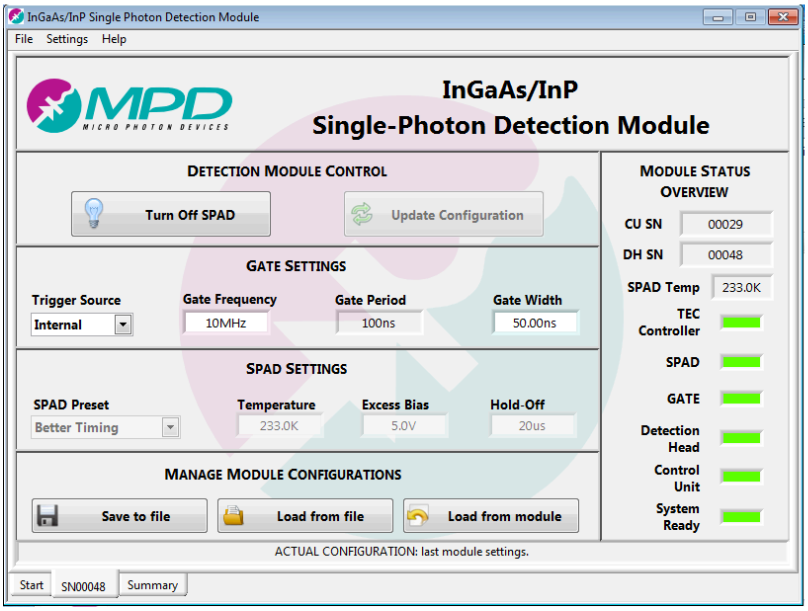


Figure 2.9. Module tab screenshot after having turned on the SPAD (with Better Timing preset).

- *Update Configuration* button: once the SPAD is on, trigger and gate parameters can be changed at user convenience. The modified values are then uploaded immediately in the module by pressing this button. Note that this button becomes active only when at least one parameter is changed since the last update. The values which have been changed, but not yet uploaded, are highlighted in blue as shown in Figure 2.8. Normally, only the Gate Settings can be changed 'on-the-fly', when the SPAD is on. Anyway, if the *Advanced* preset has been selected, also the SPAD parameters can be changed and sent immediately to the module without first turning off the SPAD (see Figure 2.10). A change of these last settings may require a detector power off and a consequent power on transient, but this is carried out automatically by the module.

- *Turn Off SPAD* button: if the SPAD is on, this button replace the "*Apply Settings and Turn On SPAD*" one. In order to shut down the detector, this button must be clicked and the user has to wait until the *SPAD* status LED, in the "*Module Status Overview*", is off.

Note

You **MUST** press *Turn Off SPAD* and **WAIT** until the *SPAD* status LED is off **before** switching off the complete module by using the power switch located on the module rear panel. **If this procedure is not followed, the SPAD detector may be permanently damaged**.

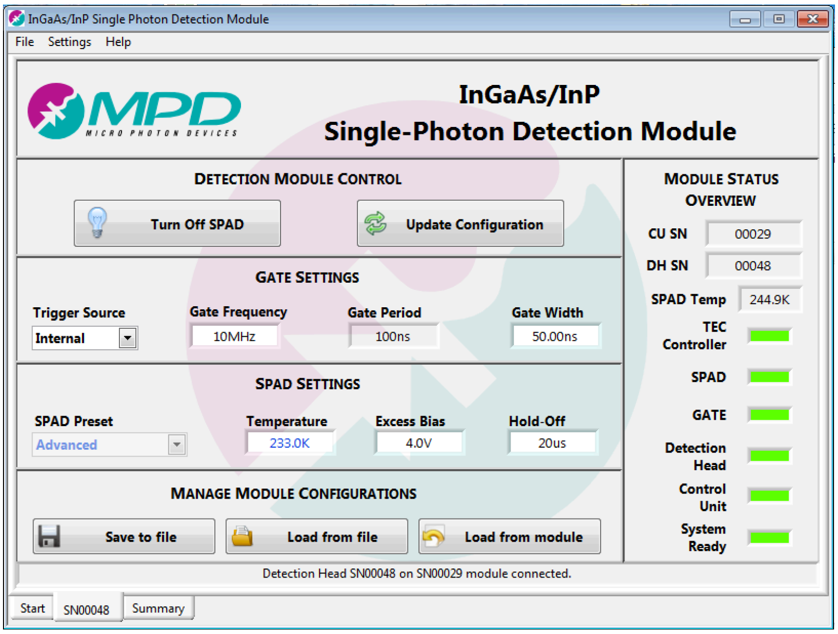


Figure 2.10. Module tab screenshot after having turned on the SPAD and with the "Advanced" "SPAD preset" selected.

2.4.2 Gate Settings

In the *Gate Settings* section, the parameters related to the gated-mode operation of this module can be set. The photodetector is only enabled for a programmable time, named *Gate Width* (T_{ON}), every time a trigger event occurs, as described in paragraph 1.5. This trigger can be externally sent to the module by the TRIGGER IN input or internally generated by the module. The *Gate Width* instead is always produced with the internal circuitry. The following section details the available controls allowed by the user interface:

- Internal Trigger:

Inside the InGaAs Single-Photon Detection Module there is a programmable trigger reference, that could be used to periodically enable the detector and also trigger an external instrumentation through the TRIGGER OUT output connector. This section is built around a high performance Phase Locked Loop, with a crystal quartz reference, which guarantees a low jitter output and a highly frequency customization.

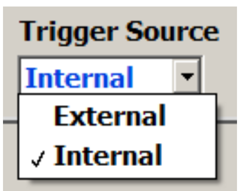


Figure 2.11. Trigger selection drop menu.

Table 2.1. *Internally available Gate Frequencies*

Frequency range	Allowable frequency
200 Hz ÷ 1 MHz	1 – 2 – 4 – 5 – 8 steps
1 MHz ÷ 25 MHz	100 kHz steps
25 MHz ÷ 133 MHz	1 MHz steps

To select this working modality, the user has to select from the *Trigger Source* drop box list, shown in Figure 2.11, *Internal source* (Figure 2.11 is an excerpt of Figure 2.8); in this manner, the configuration panel shown in Figure 2.8 and highlighted Figure 2.12 in gets active. In particular this panel is composed by two items: a control where you can specify the trigger frequency (*Gate Frequency*) in Hertz, and an indicator which, in real time, shows the inverse of the set trigger frequency, i.e. the *Gate Period*. The allowable trigger frequencies are reported in Table 2.1 and also in Chapter 4 for reference.

To confirm frequency modifications and upload them to the module, you have always to press the *"Update Gate"* button, shown in Figure 2.9, or the *"Update Parameters"* button shown in Figure 2.10

Note

The program highlights in blue all parameters that are different from the ones currently held in Control Unit. Use *"Apply Settings and Turn On SPAD"*, *"Update GATE"* or *"Update Configuration"* buttons to load new values on the module.

- External Trigger:

The module could also be triggered by an external reference signal, provided by the user. This is typical derived from the laser sync output.

Figure 2.12. *Internal Trigger configuration control and indicator.*

Figure 2.13. *External Trigger configuration controls.*

By selecting the *External source* with the menu in Figure 2.11, the panel in shown in Figure 2.10 and highlighted by Figure 2.13 will appear. With the controls in this panel, both the valid edge and the input threshold voltage can be chosen. In this way a large set of different logic levels can be accepted by TRIGGER IN input.

> **Note**
>
> By stressing the trigger input above one or more of the limiting values may cause permanent damage to the device. See Chapter 4 for more information about the absolute maximum voltage range and programmability voltage span.

- Gate Width:

The duration of the enable pulse of the SPAD detector can be set in a range of values that span over more than three decades. In particular there are two different ranges: one from 1.5 ns to 10 ns, with a programmable step of 40 ps and a second one from 10 ns up to 510 ns, with steps of 2 ns. The selection of the range is automatically chosen by the program, according to the value inserted in the *Gate Width* control, shown in Figure 2.14.

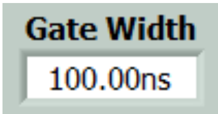


Figure 2.14. Gate width configuration.

If the *Internal Trigger* mode has been selected, the inserted value in the *Gate Width,* plus a minimum GATE-off time (see paragraph 4.5) for the detector, cannot exceed the *Gate Period*; the MPD software will automatically check if this condition is met, giving a warning message in case it is not. Otherwise, when choosing the *External Trigger* mode, the respect of this requirement must be ensured by the user. As example if the *Gate Frequency* is 133 MHz, the *Gate Period* is about 7.5 ns and thus the *Gate Width* cannot be more than 2.5 ns.

Entering the value of 0 ps as *Gate Width* lets you to disable the detector, without pressing the *"Turn Off SPAD"* SPAD. In order to re-enable it, a non-zero value must be inserted.

> **Note**
>
> If the condition (*Gate Width + Minimum Gate-OFF Time*) < *Gate Period* is not verified (external trigger), the system will return a Detection Head error.

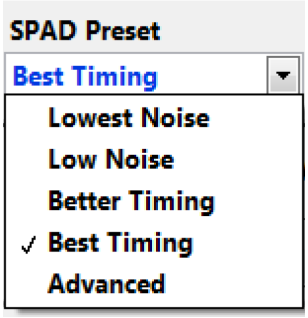


Figure 2.15. *SPAD Preset configurations drop list menu.*

2.4.3 SPAD Settings

With this panel you can select a SPAD configuration, that is a particular combination of detector temperature, excess bias and hold-off time. Under *SPAD Preset* drop list menu (shown in Figure 2.15) there are four preset configurations, which lead to different detector performances; in particular:

- Lowest Noise : it sets almost the lowest achievable DCR at the expense of detection efficiency and timing resolution;
- Low Noise : offers higher detection efficiency and still low DCR;
- Better Timing : allows to obtain high efficiency and a good temporal response (low jitter) with moderate DCR;
- Best Timing : gives you almost the best possible efficiency and timing jitter of the module at the expense of high DCR but still not the highest.

SPAD Preset selection can be changed only when the detector is off. Thus you have to use the *"Turn Off SPAD"* button if the diode is active. Modifications are applied at the next start of the detector, that is using the *"Apply Settings and Turn On SPAD"* button.

If you need a more specific configuration, there is the possibility to manually set the detector temperature, excess bias and hold-off time, by selecting the *Advanced* preset. With this preset, the *Temperature*, *Excess Bias* and *Hold-Off* controls, shown for example in Figure 2.10 and highlighted in Figure 2.16, become active and the user can enter the desired values.

Figure 2.16. *Advanced SPAD configuration, with fancy values.*

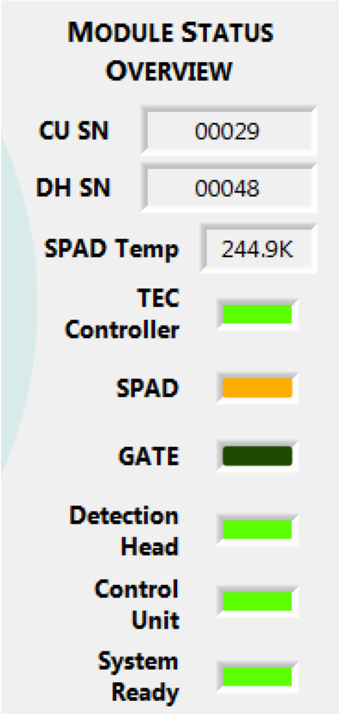


Figure 2.17. Module Status Overview indicators, during detector power on.

Normally these controls display the set values but do not allow their modification. In "*Advanced mode*", instead, you can configure these three parameters into the range and with the steps defined in the Specifications chapter. By inserting a value outside these limits, the program automatically forces the nearest allowed maximum or minimum value.

Unlike others preset, when the *Advanced* is selected, the SPAD parameters can be changed even when the detector is on and running. Modifications are applied by pressing "*Update Configuration"* button. This operation, according to the modified parameters, may require a SPAD turn off and a reactivation. Anyway this is automatically done by the module.

2.4.4 Module Status Overview

In this panel, shown for example in Figure 2.10 and depicted in Figure 2.17, there are seven status LEDs, and four other indicators. The meaning of LEDs colors are:

- *TEC Controller* LED: it turns yellow to indicate that the thermoelectric cooler has been powered on and the temperature is going to reach the desired steady state value. When the device reaches the right value, the LED becomes green. It is off while the TEC is inactive. It turns red if the desired temperature is not reached.
- *SPAD* LED: it turns yellow to indicate the transient of the SPAD bias voltage to the correct value just below breakdown and green to point out the steady state of this one.

When the bias is inactive, this LED is off. It turns red if the correct bias voltage cannot be reached.

- *GATE* LED: it turns on with a green color when the gate signal is applied to the detector; on the contrary it is inactive when the gate is off.
- *Detection Head* LED: it turns red when there is no communication with the Detection Head or when the maximum Gate Width is not satisfied (external trigger). Otherwise it is green.
- *Control Unit* LED: it turns red only when there is no communication with the Control Unit. Otherwise it is green.
- *System Ready* LED: during the normal functioning of the whole system it is green; it turns red only when an error inside the module is detected.

Others indicators in this section are:

- *CU SN* : MPD serial number of the connected Control Unit.
- *DH SN* : MPD serial number of the connected Detection Head.
- *SPAD Temp* : the current temperature of the detector in Kelvin. It is active only when the TEC controller is active; in all the other cases it does not show anything.

There is also a status bar at the bottom of the module window (shown for example in Figure 2.10): it reports the module loaded configuration or eventually the error messages.

2.4.5 Manage Module Configurations

The InGaAs Single-Photon Detection Module automatically saves and recall at startup the last settings used, but sometimes it is more convenient to save different configurations for different setups. For this purpose you can use the *Save to File* or the *Load from File* buttons, shown in all the module tab pictures and highlighted in Figure 2.18. If one of these buttons is pressed, a standard save or load window appears and it is possible to create, overwrite or open an existing file in the preferred directory.

All user data, including *SPAD settings*, *Gate Width* and the *Trigger setup* are stored in a single binary file any time the "*Save to File*" button is pressed.

In order to force the software to recall and display the parameters currently set on the module, the *Load from module* button can be used. All previous unsaved data will be lost.

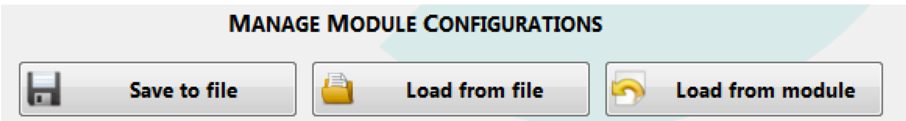


Figure 2.18. Manage Module Configurations buttons.

Note

At module startup, the last parameters, that have been successfully uploaded in the module, are automatically reloaded, shown and highlighted in blue, without the need of pressing the "*Load from module*" button.

2.4.6 Error control

In case of errors the module tab will be framed in a red rectangle. The module tab name will also turn red. A red LED in the *Module Status Overview* will mark the error type. Please refer to paragraphs 2.4.4 and 3.3 for a correct understanding of the various possible errors and for troubleshooting. In case of a communication error see immediately paragraph 3.3 before powering-off the module. In case of all the other errors the module turns off the SPAD and does not accept any more commands, thus it is necessary to switch off the module. Before switching it on and detecting it again, it is advisable to solve the cause of the error.

In some rare cases it might happen that, after having turned off the SPAD, the SPAD LED remains orange indicating that the detector's turning off procedure is taking longer than expected (see Figure 2.20). In this case please press the OK button to start an internal diagnostic routine. In case the tests will end successfully, the window shown in Figure 2.21 (left) will appear; please press OK to continue. In case the tests will end with a false alarm detection, the window shown in Figure 2.21 (right) will appear; please follow the indicated procedure in order to safely power off the module and reboot the whole detection system.

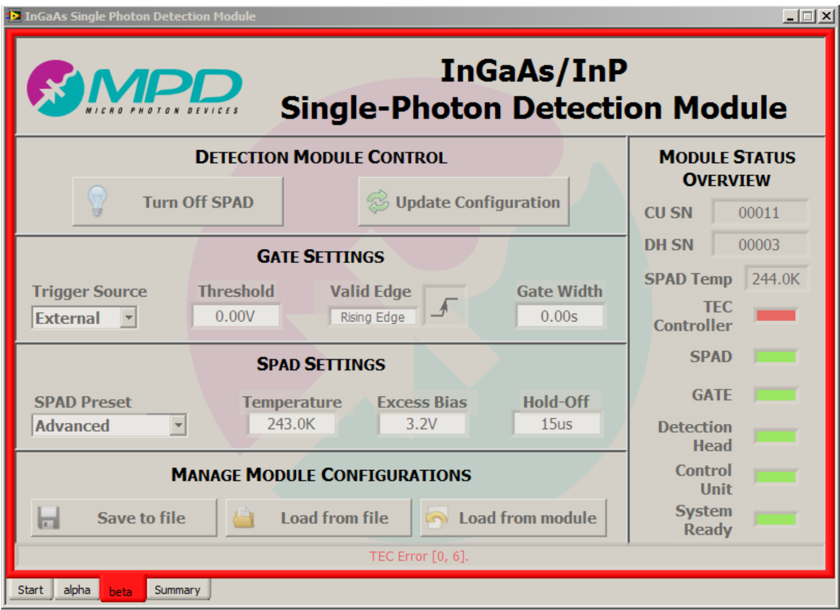


Figure 2.19. Screenshot of a Module tab when an error is detected.

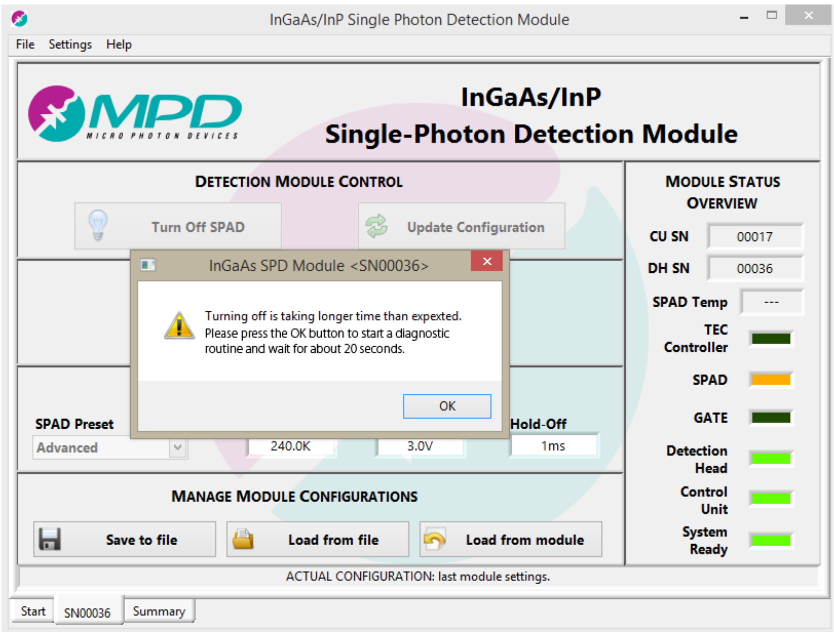


Figure 2.20. Screenshot of a Module tab when a longer-than-expected SPAD turning off time is detected.

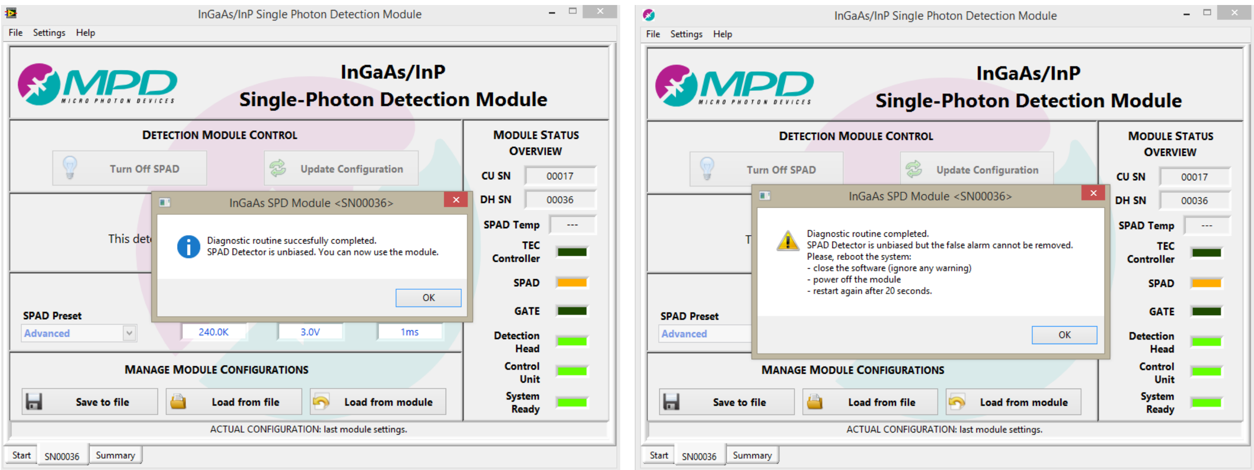


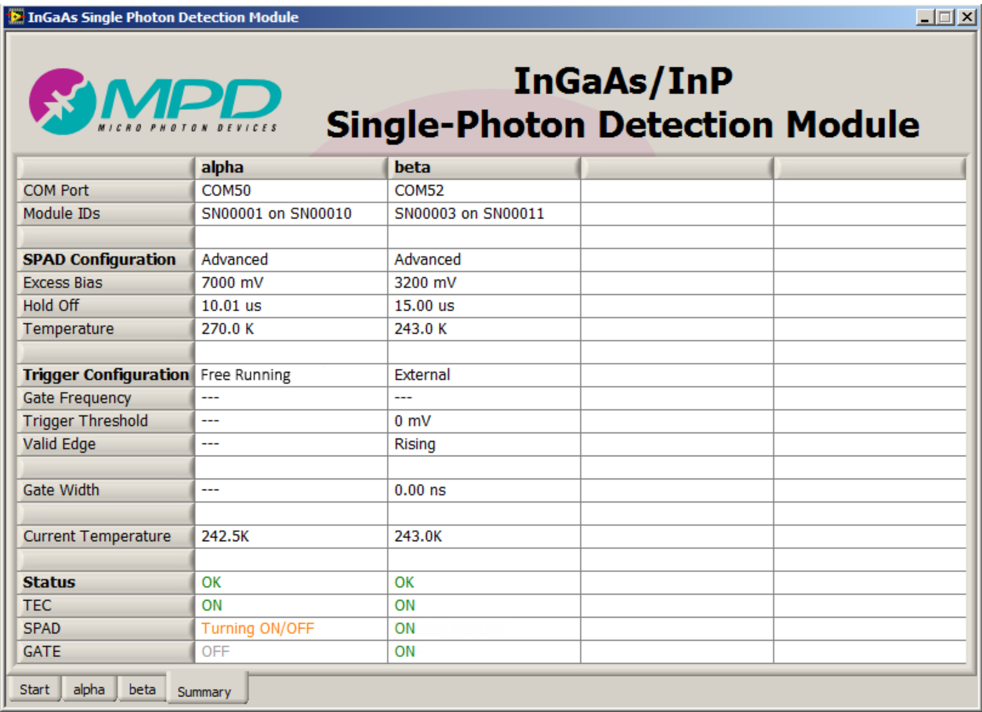
Figure 2.21. Screenshots of Module tabs showing the results of the internal diagnostic routine triggered after a longer-than-expected SPAD turning off time. Test's successful ending message is shown on the left while a false-alarm detection is shown on the right.

2.5 The Summary Tab

The Summary tab (see Figure 2.22) illustrates all parameters that have been set for each currently connected module, in a single screenshot; furthermore it reports the status of every device. Since a maximum of four InGaAs Single-Photon Detection Modules can be connected to a single PC, there are four columns that are filled with the appropriate parameter/status, indicated by the row header. Since the InGaAs control SW is able to manage both free running and gated detection heads, the Summary Tab will indicate accordingly which detection head (DH) is a free running one and which one is gated, on the line named “**Trigger Configuration**”.

This screen is only a summary, the values contained into the table cannot be modified in this tab; in order to change the parameters the correct Module Tab must be selected and the settings must be adjusted there.

The Summary Tab is only available when the software is in Multiple Module Mode, since in Single Module Mode all the reported information is already presented in the unique Module Tab present.



	alpha	beta		
COM Port	COM50	COM52		
Module IDs	SN00001 on SN00010	SN00003 on SN00011		
SPAD Configuration	Advanced	Advanced		
Excess Bias	7000 mV	3200 mV		
Hold Off	10.01 us	15.00 us		
Temperature	270.0 K	243.0 K		
Trigger Configuration	Free Running	External		
Gate Frequency	---	---		
Trigger Threshold	---	0 mV		
Valid Edge	---	Rising		
Gate Width	---	0.00 ns		
Current Temperature	242.5K	243.0K		
Status	OK	OK		
TEC	ON	ON		
SPAD	Turning ON/OFF	ON		
GATE	OFF	ON		

Figure 2.22. Summary tab showing two connected modules one with a free running detection head and one with a gated one.

Chapter

3

3 Using the InGaAs Module

In this chapter, examples of measurements and configuration procedures of the InGaAs Single-Photon Detection Module are presented.

3.1 Powering on/off and operating the InGaAs module

The following paragraphs illustrate some simple measurements in order to become familiar with the correct use and operation of the MPD InGaAs Single-Photon Detection Module.

3.1.1 Preparation for use and powering on the module

Once verified that all the items listed in paragraph 1.2.1 have been bought, it is possible to start preparing the system using the following simple steps:

1. Install the Detection Head in the optical setup, the use of the MPD universal optical table adapter is highly recommended. If the pigtailed version of the Detection Head has been bought, the loose end of the module fiber can be now connected, through the use of a barrel, to the FC/PC connector of the optical fiber coming from the experimental set-up. Before the connection please be sure to follow the care instruction listed in paragraph 1.2.3.

2. Connect the Detection Head to the Control Unit by using the orange wide-bandwidth cable and inserting it in the inlets present in the back panel of both devices. It must be ensured that the latches are both locked in the correct position. Take care in cable routing: minimum bend radius is 5 mm and first bend must be at almost 100 mm from the end connector.

3. Connect the power cord between the power inlet in the back panel of the Control Unit and the power line supply.

4. Connect the USB cable from the Control Unit to the PC.

5. Switch on the Control Unit, using the ON/OFF switch on the rear panel.

After this last operation the fan starts rotating and the module is ready to accept commands from the PC controlling program.

3.1.2 Program start and device acquisition

By following the instructions outlined in Chapter 2, the control software can be installed in the computer and then can be started. After the splash screen, reporting the software version number, the *Start Tab* will be shown. The software automatically searches the connected modules at startup so, when the splash screen disappears, all the connected modules should be displayed in the *Detected Modules* table as shown in Figure 2.1; if this does not happen, by clicking the *AutoDetect* button, it is possible to force the program to retry the search.

For each connected module a custom name can be assigned. This is very useful for identifying the correct module inside the program when controlling two or more modules with one single program; however the serial number of both Control Unit and Detection Head is also reported inside the *Module Tabs*. When all the connected modules are reported into the table and named, the *Accept Config* button has to be pressed. Now the custom names are stored in the PC and a module tab for each connected module is created (see Chapter 2 for a more detailed explanation).

3.1.3 Device configuration and detector turn-on

Before turning on the SPAD(s), for each tab relative to a connected module (or for the only visible window, when in *Single Module Mode*), these steps must be followed:

1. Make sure that *Detection Head* LED, *Control Unit* LED and *System Ready* LED are all green; they must remain green during all the system functioning. If not see the paragraph 2.4.4 and 3.3 for troubleshooting.

2. Select a *SPAD Preset*, using the menu shown in Figure 2.15. If the *Advance Mode* has been chosen, enter the desired device temperature, excess bias and hold-off time.

3. Select a *Trigger source* (internal or external) through the menu shown in Figure 2.11 and fill as desired the trigger related fields.

4. Enter a *Gate Width* in the control shown in Figure 2.14.

Completed these operations the *Apply Settings and Turn On SPAD* button can be pressed. In the next seconds some status LED will be turned on, with the following sequence:

1. The *TEC Controller* LED will become yellow and then green; during the yellow phase the detector temperature, indicated by *SPAD Temp* field, will change from the current temperature (the ambient temperature if the detector has been left off for a long time)

to the one that has been selected with SPAD Preset (or directly input in the *Advanced* mode).

2. The *SPAD* LED will become first yellow and afterwards green when the right bias voltage has been applied to the detector.

3. The *GATE* LED becomes green to indicate that the gate signal is currently applied to the SPAD.

Now the module is ready to be used in the experimental set-up. During the module functioning, the trigger and gate parameters can be easily modified, simply by changing them and uploading them to the module through the *Update Configuration* button. Before changing the SPAD Preset currently in use, the SPAD must be tuned off by using the *Turn Off SPAD* button.

3.1.4 End of measure and powering off the module

When the measurement ends and the InGaAs Single-Photon Detection Module is not needed anymore, the module must be powered down correctly in order to prevent detector damages. The correct procedure is the following one:

1. Press the "*Turn Off SPAD"* button and wait until the SPAD LED goes off.

2. Repeat this operation for any connected module thought the respective module tab.

3. When all the SPADs have been turned off, close the program. A message warns the user if there are modules still running when the software is closed. If this happens please go back to the software and turn off these SPADs or **carefully** read the following chapter 3.1.5 if you want use them in the *standalone mode*.

4. It is now possible to press the power switch, located in the back panel of each module, in order to physically switch off the module.

5. Before powering on again a Detection Module, please wait for at least 20 seconds.

If the power switch is pressed before the closing of the software, a warning window will signal that there is a communication problem. This warning can, in this case only, be ignored.

3.1.5 Standalone module use (use with extreme caution)

The InGaAs Single-Photon Detection Module can also be operated without a PC constantly connected. In fact when the module is properly configured and the detector is biased correctly, it can be detached from the PC, removing the USB cable, while it still runs: the module can work without the need of the PC connection. This is particularly useful when long measurements have to be performed and other instruments do not require a supervisor PC. However the customer must be *extremely careful* when this modality is used: the status of the module cannot be monitored through the control software and, since the detector is biased, the module cannot be switched off through the power switch. In order to safely power off the system, the module **must** be reconnected to the PC, detected with the procedure described in Chapter 3.1.2 and correctly turned off using the procedure described in Chapter 3.1.4 (otherwise the SPAD might be ***permanently damaged***). If during the standalone functioning some errors occur, they will be reported after the device detection procedure.

Note

When the USB cable is detached form the module with a biased detector a Communication Error occurs: this errors signals that the module is still operating and that ***it has to be to reconnected later to the PC in order to turn the SPAD off correctly***.

3.2 Basic Setups

In this section simple test measurements are outlined and briefly explained.

3.2.1 Photon Counting setup

Photon-counting is the simplest measurements performable with the module and Figure 3.1 shows a possible example of an experimental setup. It consists of a continuous wave laser that produces photons at 980 nm, properly attenuated, and a sample that absorbs photons and re-emits in the near infrared range. These photons, properly collected, are sent to the SPAD detector (inside the Detection Head).

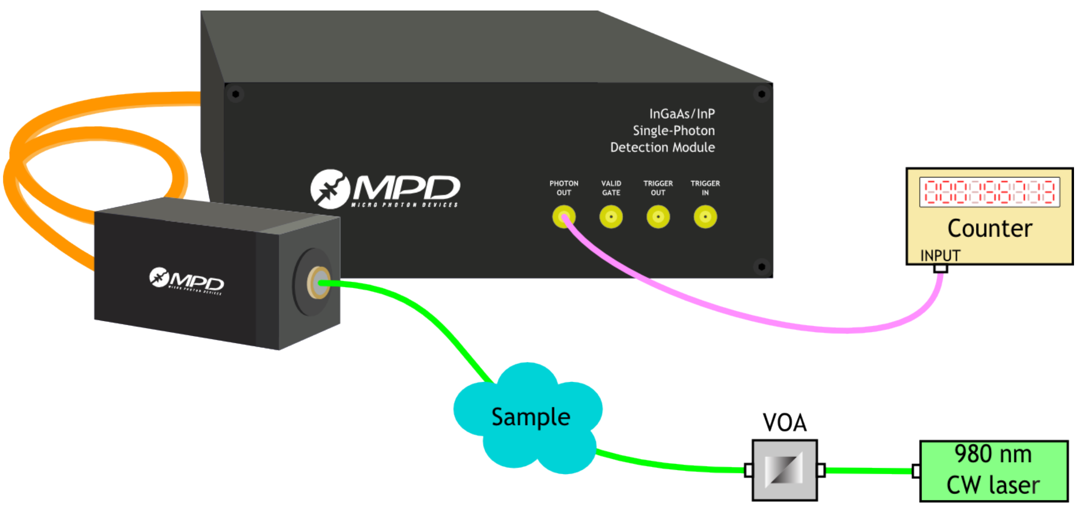


Figure 3.1. Simple setup for a photon-counting measure (green: optical signals, pink: electric signals).

The module is configured to operate with the internal trigger and its photon-out output is connected to a counter, that calculates the number of photons per seconds (i.e. counts per seconds, cps).

As already explained in paragraph 1.5, since after every detected photon the SPAD must be kept disabled for a certain amount of time (hold-off time), the effective enabling frequency of the detector is not the *Gate Frequency*. We can simply estimate the effective trigger frequency f_{EFF} through the following simple formula:

$$f_{EFF} = f_{TRIG} \cdot (1 - CR \cdot T_{HO})$$

where f_{TRIG} is the *Gate Frequency* defined into the control software, CR is the count rate or the detected photons (indicated by the counter) and T_{HO} is the hold-off time, which is also defined through the control software.

If we are interested in the number of photons that impinge on the sensor in a unitary time, we can use the approximate equation (see paragraph 1.5) :

$$N_{PH} \cong \frac{T}{\eta(\lambda) \cdot T_{ON}} \cdot \frac{CR}{1 - CR \cdot T_{HO}}$$

where $\eta(\lambda)$ is the Photon Detection Efficiency of the SPAD at the operating wavelength and T_{ON}/T is simply the duty-cycle D at which the SPAD is switched on/off.

3.2.2 Photon Timing setup

Another typical setup in which the InGaAs Single-Photon Detection Module is used is a photon-timing one, illustrated in Figure 3.2. This setup can be adopted for the measurement of fast waveforms of repetitive optical pulses. The technique is commonly known as Time Correlated Single Photon Timing (TCSPC) and is extensively described in ref. [1] and [2]. This setup consists of a pulsed laser source which excites a fluorescent sample that reemits photons with an exponential decay. In this example the module is still internally triggered but the trigger-out of the module is connected to the trigger-in of the laser. In this way the laser is triggered by the InGaAs module. This trigger-out signal of the laser is then used, as START of a TCSPC system. The STOP signal to the TCSPC system is given by the photon out of the Control Unit. Please note that it might be necessary to invert the trigger-out pulse in order to synchronize the laser on the correct signal edge. For example, in case of using a PicoQuant PicoHarp 300 [3], the laser sync is usually connected the Channel 0 input and the photon out is normally connected to the Channel 1 input. If the B&H SPC-130 [4] or similar cards are employed instead, please read carefully their manual because these cards work in the so called reverse mode. When connecting all the instruments it is very important to verify the voltage levels and the polarity of all the involved signals and to attenuate/invert them if necessary in order to comply with the inputs' absolute maximum ratings.

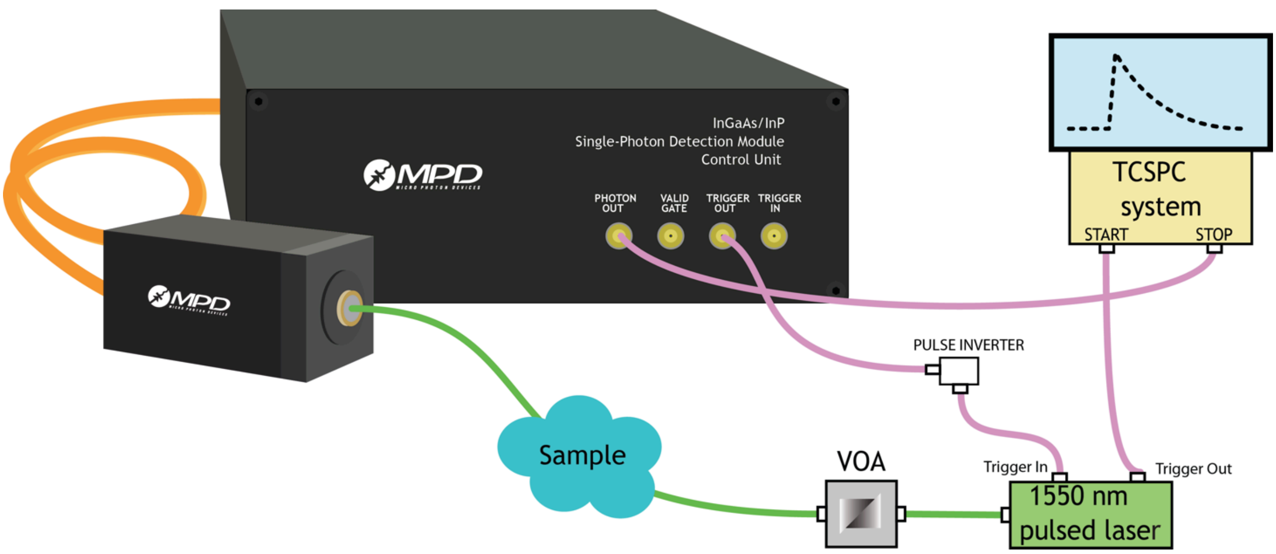


Figure 3.2. Simple setup for a photon-timing measure (green: optical signals, pink: electric signals).

In order to ensure that the photons emitted by the sample impinge on the detector when the gate has been enabled, it is necessary to take particular care to the signal propagation delays inside the cables and in the instruments, included the InGaAs control unit (see Chapter 4 for the actual numbers).

In this case all the equations used in the previous example are still valid and can be used in order to calculate the actual counting rate of the detector. Anyway, the TCSPC technique is normally adopted in order to correctly reconstruct the shape of the temporal response of fast pulses or a fast decaying fluorescence pulses (like in our example) by accurately measuring the photon arrival times and not simple measuring number of counts in a period of time. In order to do this, using the TCSPC technique, it must be guaranteed that only a single photon reaches the detector for every single gate. This is commonly known in the scientific literature and is explained in ref. [1] and [2]. In order to avoid the pile-up effect [1] the detection rate of the laser trigger frequency must be lower than 5 % (or better 1%).

In order to obtain the correct equations the module duty cycle D should not be considered: the reason relies in the fact that the Gate window is synchronized with the laser optical pulse and thus all the laser photons reach always the detector when the detector is on: the correction due to the gate mode does not apply because for the laser pulses the SPAD behaves as if operated in free running. Only the correction for the hold-off time must be implemented. In addition we will consider negligible the effect of the DCR and of the afterpulsing: the minor error that is committed is conservative in calculating the correct counting-rate for avoiding the pile-up effect.

As a consequence the light source must be properly attenuated in order to satisfy the following condition: the module count rate should be smaller than 5% (or 1%) of the valid laser frequency (f_{EFF}), i.e. the equivalent one considering only the laser pulses that were shined when the module was in the ON state, i.e. :

$$CR < 5\% \cdot f_{EFF} = 5\% \cdot \left(f_{laser} - CR \cdot \frac{T_{HO}}{D_{laser}}\right) = 5\% \cdot (f_{laser} - f_{laser} \cdot CR \cdot T_{HO})$$

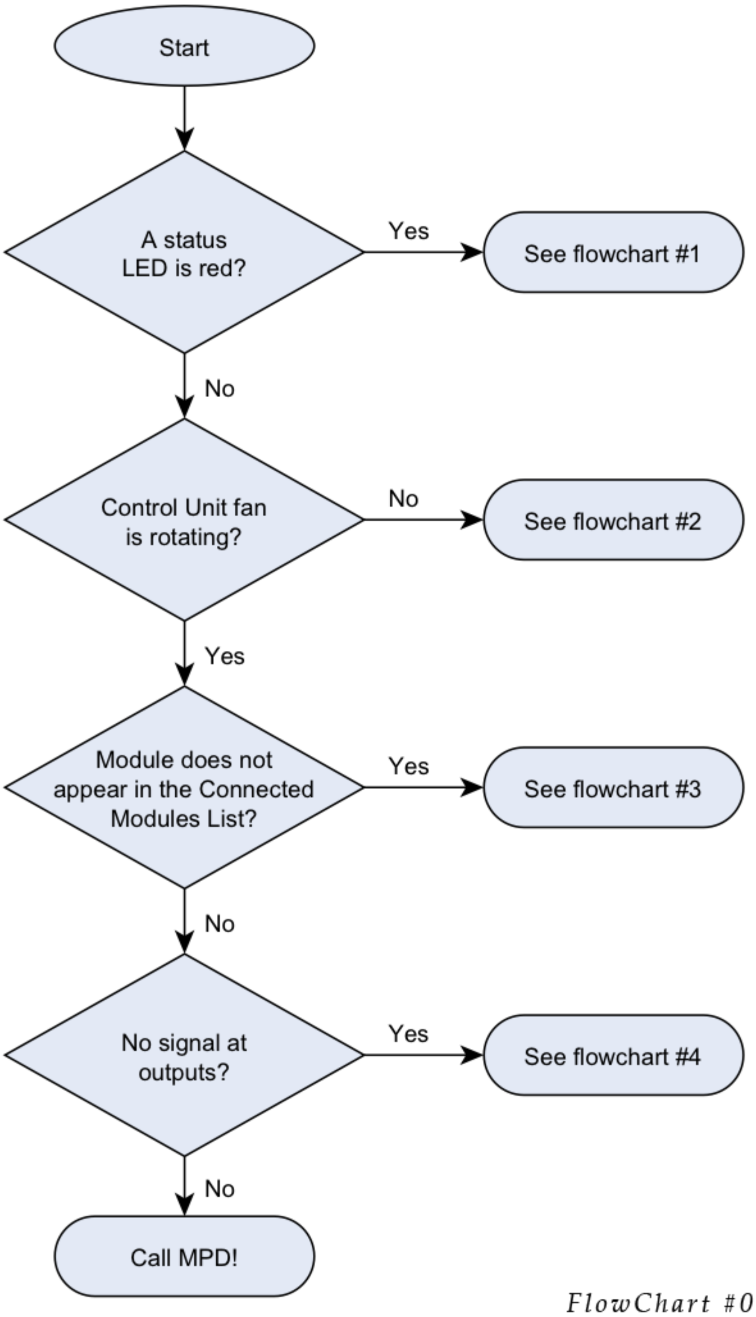
and thus simplifying:

$$\frac{CR}{1 - CR \cdot T_{HO}} < 5\ \% \cdot f_{laser}$$

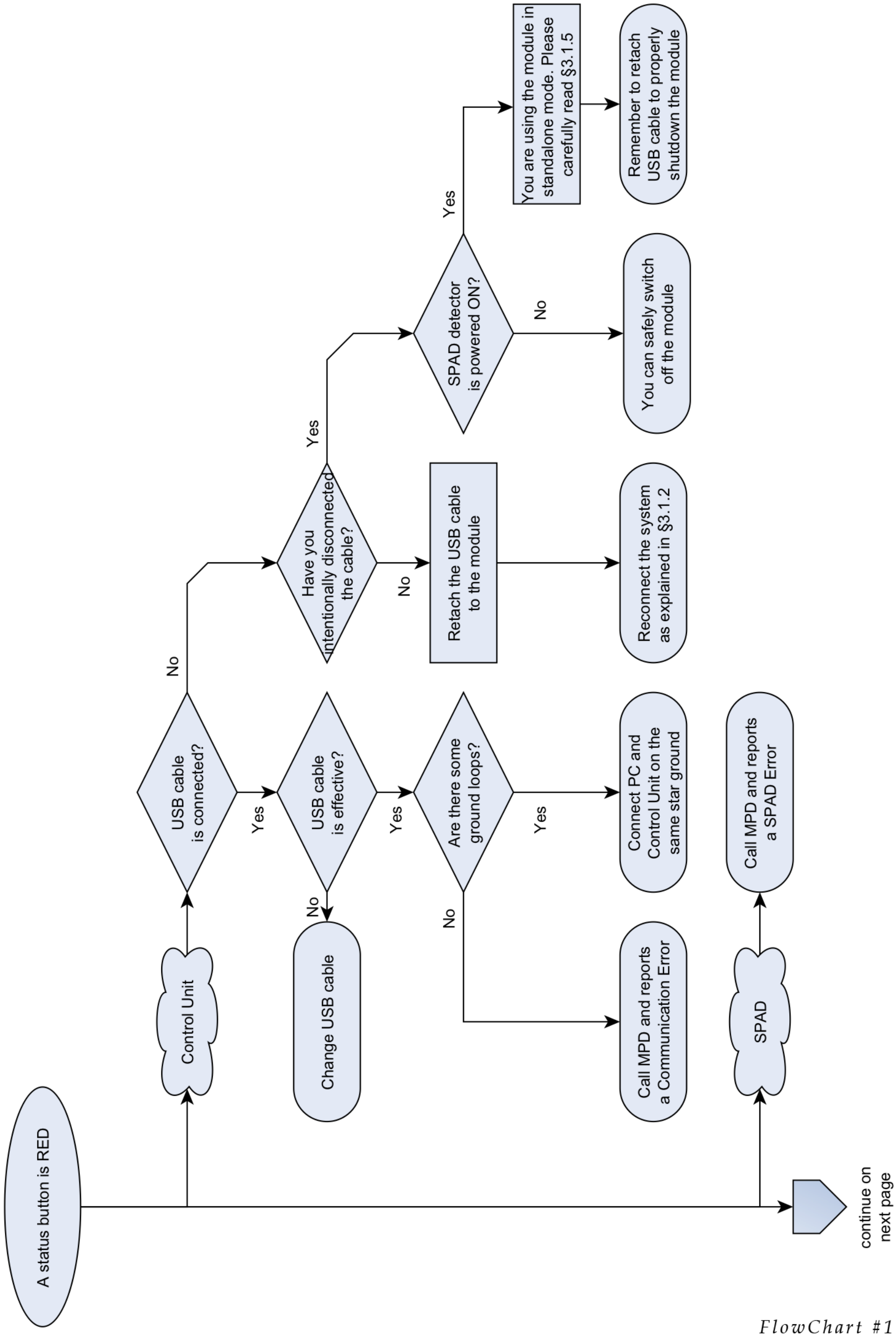
where $D_{laser} = {}^{1}/_{f_{laser}}$, T_{HO} is the hold-off time and CR is the actual module counting rate as measured at a counter.

3.3 Troubleshooting

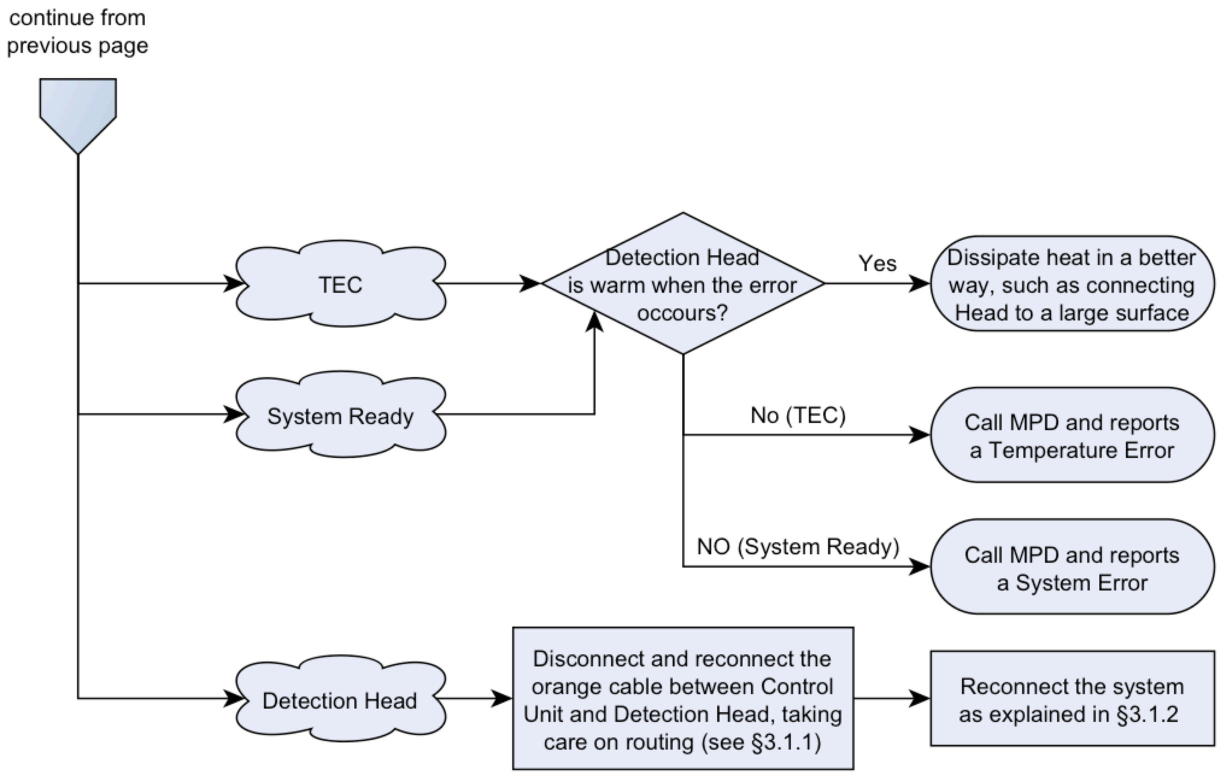
Whenever a problem occurs during the use of the InGaAs single photon counter, please follow the directions contained in FlowChart #0. Please call MPD for assistance only if your problem is not listed here, if the flowchart directly tells you to do so or if the error persists despite the troubleshooting efforts.

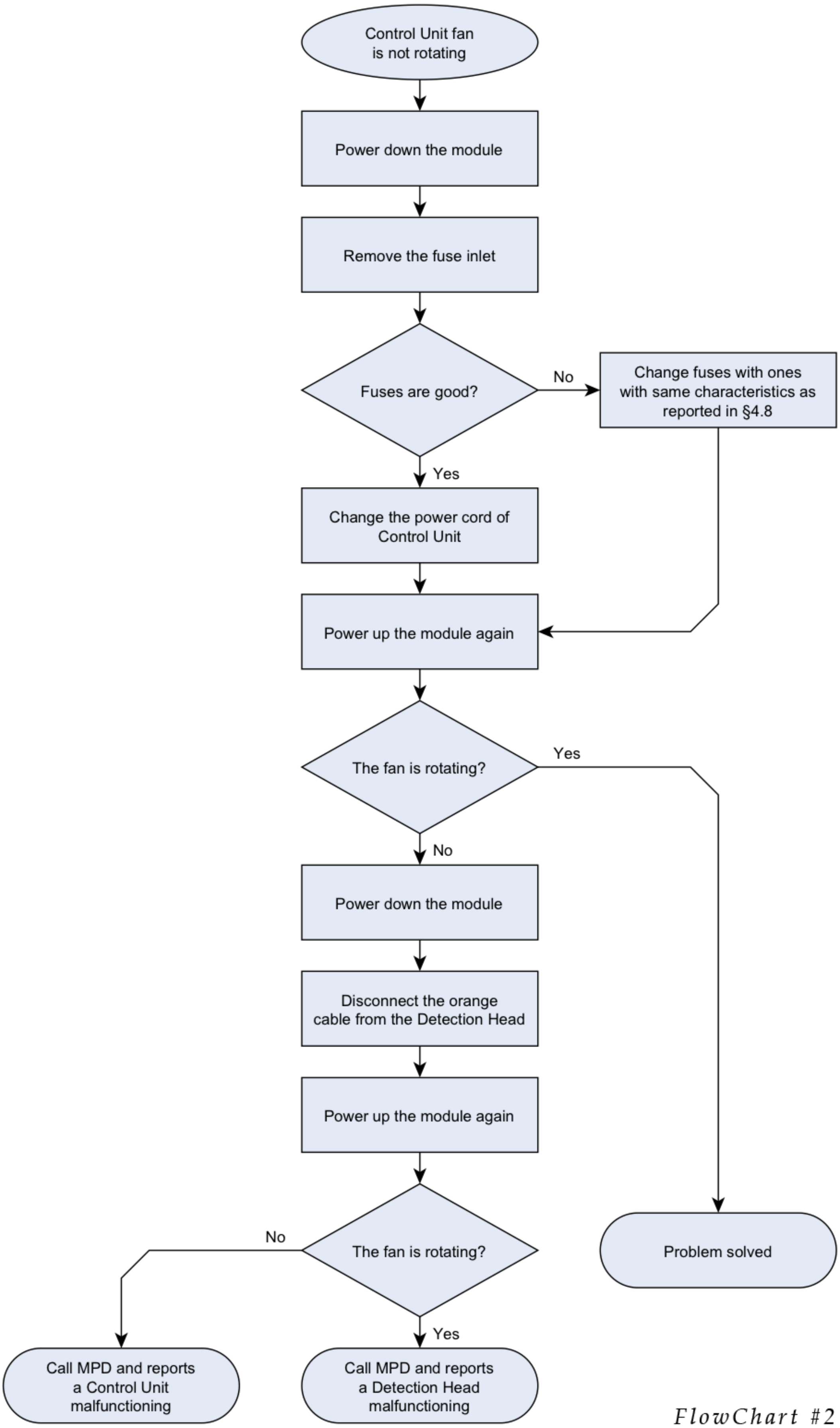


FlowChart #0

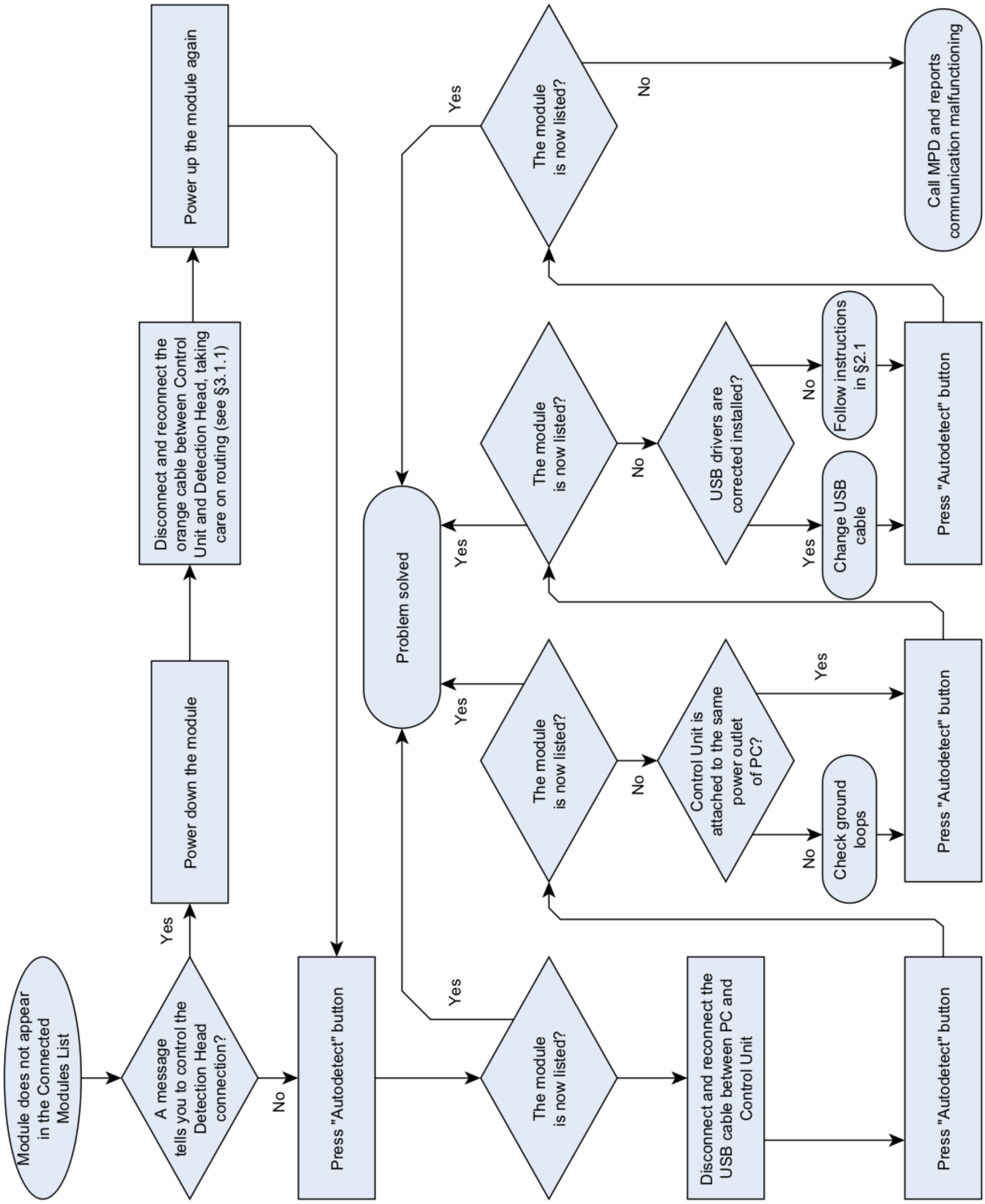

A status button is RED
Control Unit
USB cable is connected?
Yes
No
USB cable is effective?
Change USB cable
Are there some ground loops?
Connect PC and Control Unit on the same star ground
Call MPD and reports a Communication Error
Have you intentionally disconnected the cable?
Retach the USB cable to the module
Reconnect the system as explained in §3.1.2
SPAD detector is powered ON?
You can safely switch off the module
You are using the module in standalone mode. Please carefully read §3.1.5
Remember to retach USB cable to properly shutdown the module
SPAD
Call MPD and reports a SPAD Error
continue on next page

FlowChart #1

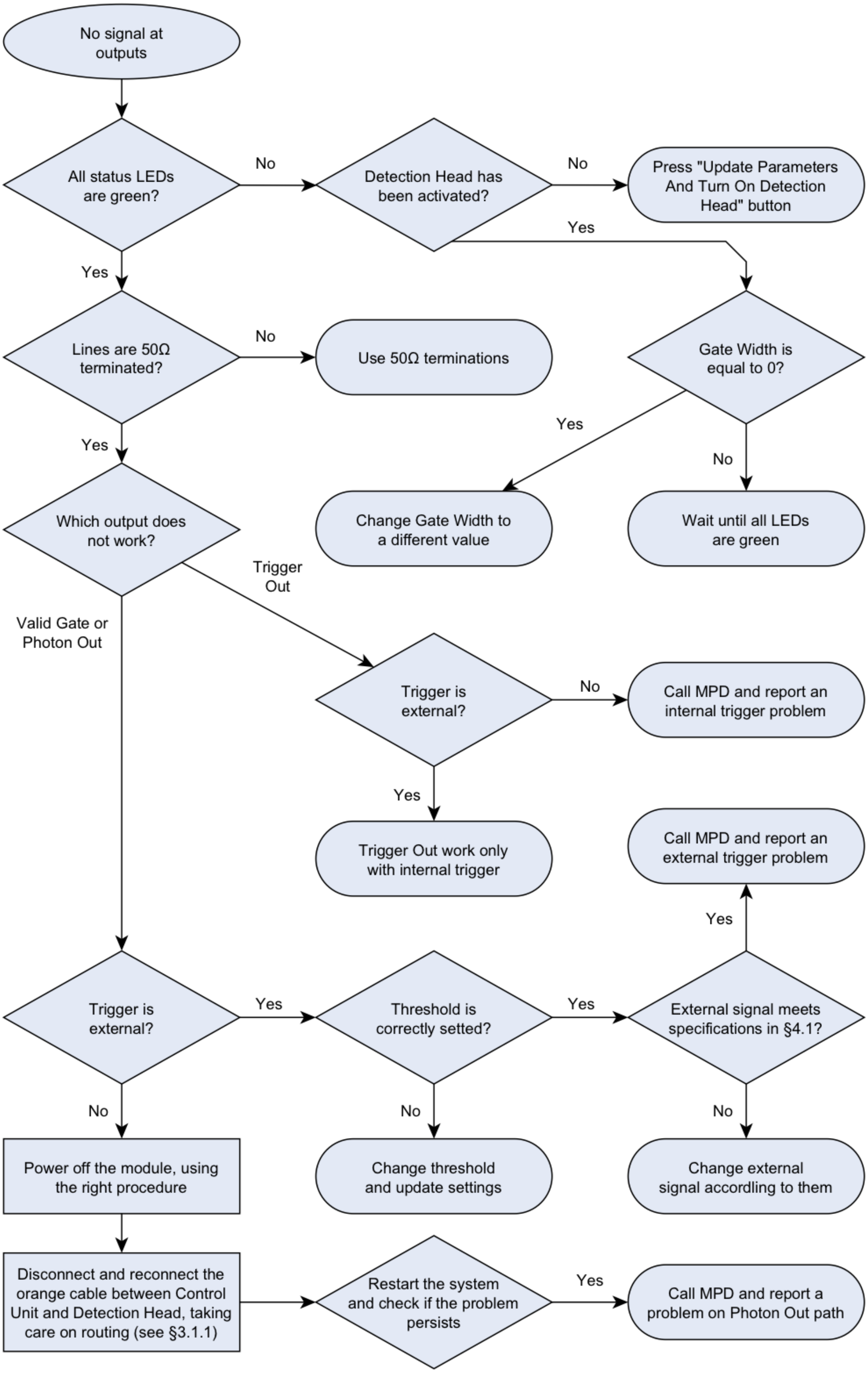

continue from
previous page
TEC
System Ready
Detection Head
is warm when the error
occours?
Yes
Dissipate heat in a better
way, such as connecting
Head to a large surface
No (TEC)
Call MPD and reports
a Temperature Error
NO (System Ready)
Call MPD and reports
a System Error
Detection Head
Disconnect and reconnect the
orange cable between Control
Unit and Detection Head, taking
care on routing (see §3.1.1)
Reconnect the system
as explained in §3.1.2


Control Unit fan
is not rotating
Power down the module
Remove the fuse inlet
Fuses are good?
No
Change fuses with ones
with same characteristics as
reported in §4.8
Yes
Change the power cord of
Control Unit
Power up the module again
The fan is rotating?
Yes
No
Power down the module
Disconnect the orange
cable from the Detection Head
Power up the module again
No
The fan is rotating?
Problem solved
Yes
Call MPD and reports
a Control Unit
malfunctioning
Call MPD and reports
a Detection Head
malfunctioning

FlowChart #2


Module does not appear in the Connected Modules List
A message tells you to control the Detection Head connection?
Yes
No
Power down the module
Disconnect and reconnect the orange cable between Control Unit and Detection Head, taking care on routing (see §3.1.1)
Power up the module again
Press "Autodetect" button
The module is now listed?
Yes
Disconnect and reconnect the USB cable between PC and Control Unit
Press "Autodetect" button
Problem solved
The module is now listed?
Yes
No
Control Unit is attached to the same power outlet of PC?
Yes
No
Check ground loops
Press "Autodetect" button
The module is now listed?
Yes
No
USB drivers are corrected installed?
Yes
No
Change USB cable
Follow instructions in §2.1
Press "Autodetect" button
The module is now listed?
Yes
No
Call MPD and reports communication malfunctioning

FlowChart #3



No signal at outputs
All status LEDs are green?
No
Detection Head has been activated?
No
Press "Update Parameters And Turn On Detection Head" button
Yes
Yes
Lines are 50Ω terminated?
No
Use 50Ω terminations
Gate Width is equal to 0?
Yes
No
Yes
Which output does not work?
Change Gate Width to a different value
Wait until all LEDs are green
Trigger Out
Valid Gate or Photon Out
Trigger is external?
No
Call MPD and report an internal trigger problem
Yes
Trigger Out work only with internal trigger
Call MPD and report an external trigger problem
Yes
Trigger is external?
Yes
Threshold is correctly setted?
Yes
External signal meets specifications in §4.1?
No
No
No
Power off the module, using the right procedure
Change threshold and update settings
Change external signal accordling to them
Disconnect and reconnect the orange cable between Control Unit and Detection Head, taking care on routing (see §3.1.1)
Restart the system and check if the problem persists
Yes
Call MPD and report a problem on Photon Out path

FlowChart #4

3.4 Bibliography

[1] Lakowicz, J. R., Priciples of Fluorescence Spectroscopy, 3rd Edition, Springer, New York, 2006.

[2] O' Connor, D.V.O., Phillips, D., Time-correlated Single Photon Counting, Academic Press, London, 1984.

[3] PicoHarp 300 by PicoQuant GmbH. http://www.picoquant.com/products/picoharp300/picoharp300.htm

[4] SPC-130 by Becker and Hickl GmbH. http://www.becker-hickl.de/tcspc.htm#spc130

Chapter 4

4 Specifications

The specifications of the InGaAs Single-Photon Detection Module are provided in this chapter.

4.1 Instrument Input (Trigger IN)

Note: Do not use when the control unit is connected to Free-running detection head.

Impedance	50 Ω	
Coupling	DC	
Frequency Range[1]	DC to 133 MHz DC to 25 MHz	if T_{ON} < = 10 ns if T_{ON} > 10 ns
Input Level	Range: Damage:	−2 V ÷ 2.5 V ± 5 V
Minimum Slew Rate	5 V/µs	
Threshold Level	Range: Resolution: Accuracy:	−2 V ÷ 2.5 V 18 mV ± 30 mV
Trigger Slope	Positive or Negative	
Minimum Pulse Width	2 ns	

4.2 Instrument LVTTL Outputs (Trigger Out – Valid Gate)

Note: when the CU is connected to a Free-running detection head, Trigger Out is disabled.

Amplitude	0 ÷ 3.3 V ± 400 mV
Required Load	50 Ω fixed DC impedance
Rise/Fall Time (20 ÷ 80 %)	1 ns
Valid Edge	Positive

[1] Maximum frequency also limited by condition $1/f_{TRIG} > T_{ON}$ + min. GATE–OFF time (see paragraph 4.5)

4.3 Instrument NIM Output (Photon Out)

Amplitude	0 ÷ -16 mA on 50 Ω: 0 ÷ -0.8 V
Required Load	50 Ω fixed DC impedance
Valid Edge	Negative
Falling Time (20 ÷ 80 %)	400 ps
NIM pulse width	12 ns ± 2 ns

4.4 Internal Trigger

Note: Not enabled if the CU is connected to a free running detection head.

Frequency range	200 Hz to 133 MHz	
Time-base stability	50 ppm	
Duty Cycle	50 % ± 5 %	
Output frequencies	under 1 MHz:	200 – 400 Hz – 500 – 800 Hz 1 – 2 – 4 – 5 – 8 kHz 10 – 20 – 40 – 50 – 80 kHz 100 – 200 – 400 – 500 – 800 kHz
	from 1 to 25 MHz:	100 kHz steps
	over 25 MHz:	1 MHz steps
Cycle-to-cycle jitter (peak-peak)	< 100 ps	

4.5 Gate Window and Hold-Off programmability

Note: Gate window is meaningless for a Free-running detection head.

Gate Width (T_{ON})	1.5 ns ÷ 10 ns: 10 ns ÷ 500 ns:	40 ps steps 2 ns steps
Gate Width Accuracy (DNL)	1.5 ns ÷ 10 ns: 10 ns ÷ 500 ns:	± 40 ps ± 500 ps
Gate rise/fall time (20%-80%)	700 ps (typ.)	1500 ps (max)
Hold-Off Time	1 μs ÷ 3 ms	24 ns steps
Hold-Off Time Accuracy		± 3.5 ns
Excess Bias range	2 V ÷ 7 V 2 V ÷ 5V	Gated mode Free running mode
Minimum Gate – OFF time	5 ns 15 ns 30 ns	if T_{ON} < = 10 ns if 10 ns < T_{ON} < = 100 ns if T_{ON} > 100 ns

4.6 Signal Propagation Times

In Figure 4.1 are reported the most important waveforms related to the InGaAs Single-Photon Detection Module that help the user to understand correctly the various internal and external signal propagation delays. In Table 4.1 are reported the delays between these signals, in various operating conditions.

- TRIGGER SIGNAL:
  - in *gated mode*, it is the signal designated to be the reference; it could be the internal trigger or the external one supplied by the user. Note that the delay varies according to the selected trigger source. Anyway reported delays are related to the respective front panel measured signal (i.e. TRIGGER OUT or TRIGGER IN);
  - in *free-running mode* this signal is disabled, the SPAD is always on, it is quenched only if an avalanche occurs and it is enabled immediately at the end of each hold-off time.
- GATE WINDOW:
  - in *gated mode*, it is the SPAD enable signal, measured directly on the detector. Note this signal cannot be directly measured by the user;
  - in *free-running mode*, the "Gate" signal is off during the hold-off time only, otherwise it is on.
- AVALANCHE SIGNAL: it is the SPAD output signal, asserted when a photon is absorbed by the device. This is an internal signal that cannot be measured by user.
- PHOTON OUT: it is the front panel output which marks a detected incoming photon.
- VALID GATE:
  - in *gated mode*, it is the front panel output which reports which Gate windows are effectively applied to the SPAD and are not masked during the hold-off time. Normally *Gate Frequency* and VALID GATE are matched, but during hold-off time the *Gate Frequency* (trigger signal) is masked and this output remains into the low logic state (see paragraph 1.5 of the gated mode user manual);
  - in *free-running mode*, the Valid Gate signal outputs the effective SPAD status, i.e. when it is ON or OFF due to the hold-off.

Table 4.1. Signal propagation times into different operating conditions.

Condition		t_1	t_2	t_3
External Trigger	$T_{ON} \leq 10$ ns	35.7 ns ± 10%	11.3 ns ± 10%	14.3 ns ± 5%
	$T_{ON} > 10$ ns	52.7 ns ± 10%		
Internal Trigger	$T_{ON} \leq 10$ ns	25.0 ns ± 10%		
	$T_{ON} > 10$ ns	40.9 ns ± 10%		

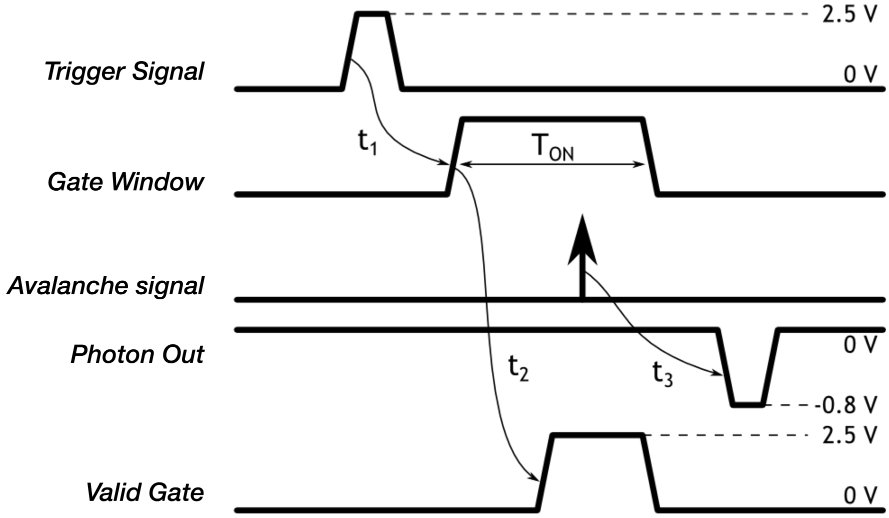


Figure 4.1. Signals waveform, with delay times highlighted.

4.7 Detector

Detector size	25 µm	
Photon Detection Efficiency (@ 1550 nm, V_{EX} = 2.5 V)	12% typ. 15% typ.	Fiber pigtailed Free space
Temperature range[2]	228 K ÷ 290 K 228 K ÷ 243 K	Gated mode Free-running mode
Temperature resolution	0.1 K	
SPAD performances	Max DCR (@ T=233 K, V_{EX}=2.5 V)	Grade A < 40 kc/s Grade B < 20 kc/s Grade C < 10 kc/s
	Typ. FWHM (@V_{EX}=7 V)	< 100 ps (Fiber pigtailed) < 150 ps (free space)[3]
Electronics intrinsic jitter	30 ps (checked with silicon SPAD)	
Maximum Optical Power	1 mW (CW – Continuous Wave)	
The InGaAs/InP SPAD is not damaged by accidental exposure to room light		
Optical Interface (free space)	The distance from the top of the cap to the active area is 2.9 mm and the glass-window is recessed approximately 0.75 mm so the distance from the detector surface to the outside surface of the glass window is about 2.15 mm.	
Optical Interface (pigtail)	single mode SMF-28 fiber with FC/PC connector	

[2] *Detector minimum temperature may depend both on operating environment temperature and Detection Head case power dissipation. Please improve thermal conduction if a TEC Error occurs.*

[3] *With not-focalized beam. Can be lowered if light is focalized on a small area.*

4.8 General Specifications

Control Unit Dimensions	235 mm x 250 mm x 90 mm
Detection Head Dimensions	60 mm x 60 mm x 120 mm
Weight	2.5 kg maximum
Power Supply Voltage	100 to 240 VAC – 50/60 Hz
Continuous Power Requirements	15 VA maximum
Power-Line Fuse	1 A, 250 V
Operating Environment	10° C to 25° C
Storage Environment	0° C to 70° C
Remote Interface	USB 1.1., 2.0

4.9 System Requirements for Software

Operating system (Microsoft® Windows® only)	• 8/7/Vista: both 32 and 64 bit • XP/Server 2003 R2: only 32 bit • Server 2008 R2: only 64 bit
Minimum recommended system requirements	• Pentium 4 or equivalent processor • 500Mb or 1 GB of RAM • 1 GB of free disk space • 1024 x 768 pixel display resolution • USB 1.1 or 2.0 port

5 Changelog

1.0	first MPD version
1.1	added the Hold Off specifications
1.2	minor revisions
	corrected LVTTL outputs specifications
	corrected OUTPUTS load specifications
	updated sections on SPAD characteristics and system requirements
1.3	corrected the Gate Width specifications
1.4	corrected error in gate width accuracy
1.5	corrected wrong description of VALID GATE (sentence moved to TRIGGER OUT description)
	now the NIM output pulse width and the excess bias range are specified
	updated figure 4.1 and tables 4.4 and 4.7
	updated the gate-off minimum requirements (enforced by software version >= 5.0.7)
	other minor corrections
1.6	corrected windows driver installation procedure
	added info on the optical interfaces
	added suggestion waiting for at least 20s before powering on again a module after power off.
4.0.1	updated for new software interface (v4.3.1)
	corrected minor error in the 5% TCSPC equations
	updated sections which are now in common with the free-running version
4.0.2	updated gated-off time characteristics
	expanded error section
	changelog is now included inside this manual