Test Bench Manual

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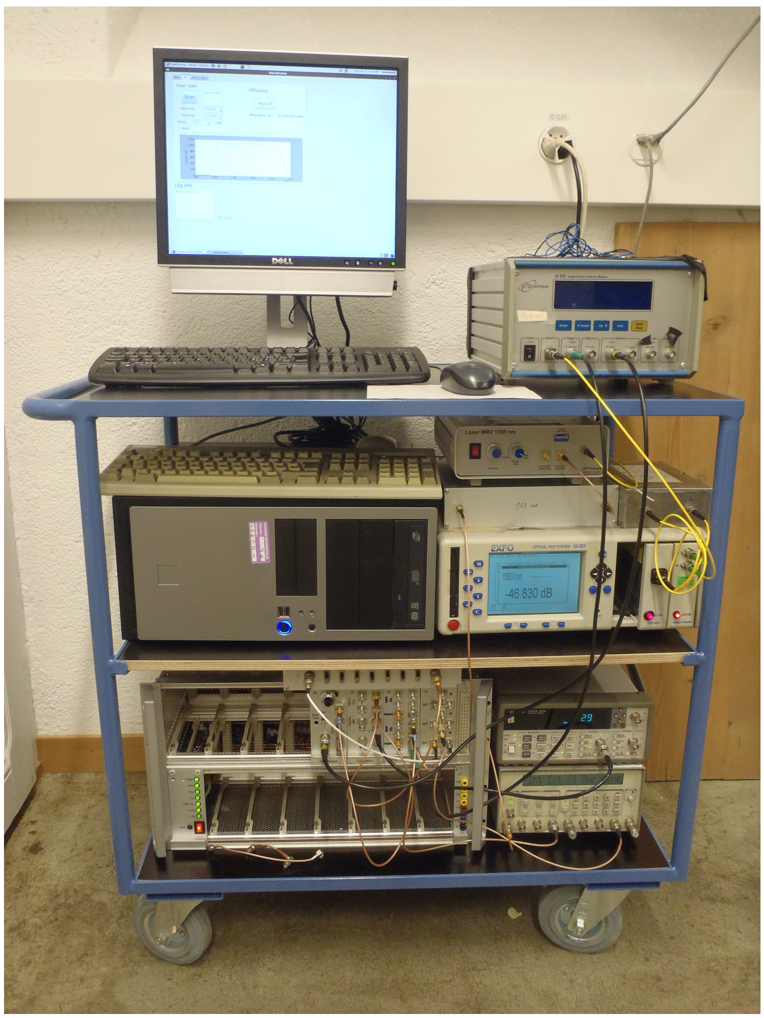

1 Specifications

Parameter	*Value*
General	
Detector Type	Gated Mode Detectors, Free-running detectors
Detector Trigger Input	TTL, NIM, ECL
Pulse Generator	
Maximum Frequency	1 MHz
Maximum Delay	1000 sec
Resolution	5 ps
Accuracy	1500 ps
Laser	
Wavelength	1550 nm
Pulse Width (FWHM)	490 ps
Counter	
Signal Input	TTL, NIM, ECL

2 Preliminary Remark

The test bench setup can characterize the efficiency, dark-count rate and afterpulsing of gated detectors. Moreover it can also characterize efficiency and dark count rate of free-running detector if the afterpulsing probability and the dead time are provided by the user. Before to do the characterizations check that the right setup is installed: to characterize a gated detector install the setup 1 (Sec.6). For a free-running detector install setup 2 (Sec.8).

3 Setup

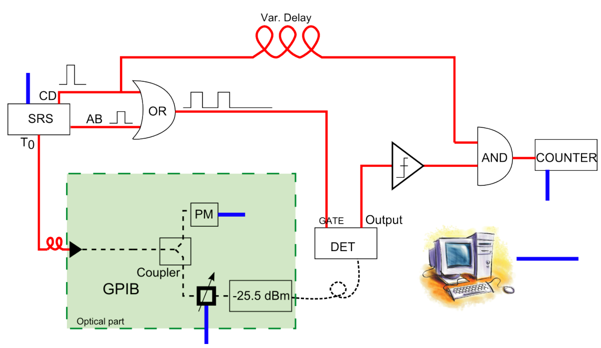

Figure 1: Setup 1 for characterizations of gated detectors

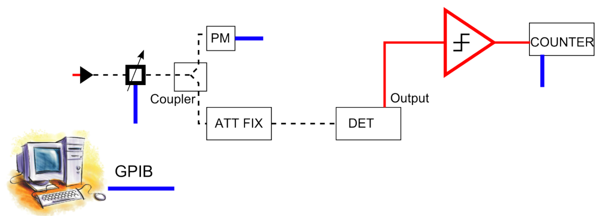

Figure 2: Setup 2 for characterizations of free-running detectors

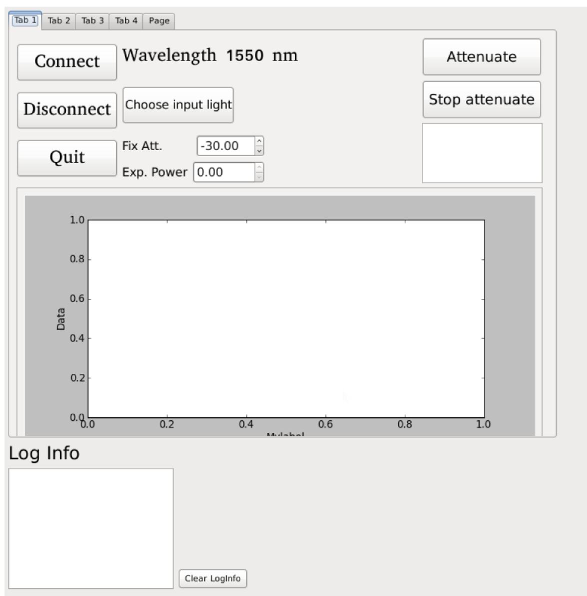

Figure 3: Tab 1 of main control program. Optical pulse attenuation settings.

4 Software

The main test bench control software has a Python user interface and comprises of 4 tabs, which are illustrated in Figures 3, 4 5, 6, 7 and8.

Preliminary

5 PC

- Turn on the PC and log on.
  - Username = TESTBENCH
  - Password = tb

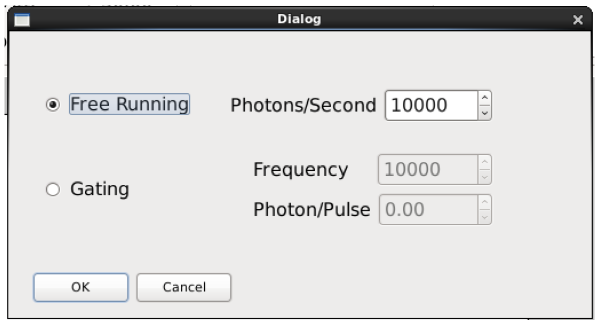

Figure 4: Sub-tab of main control program. In this sub-tab you choose the photon settings for the characterizations.

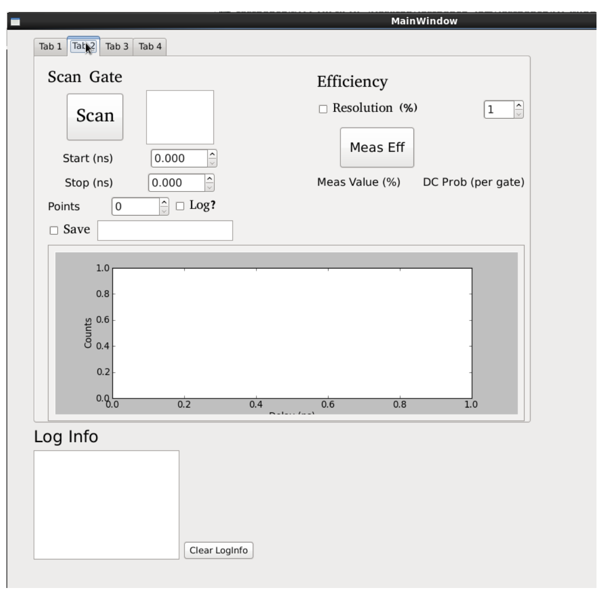

Figure 5: Tab 2 of main control program. Detector efficiency, dark count and scan of the gate characterization, settings and results.

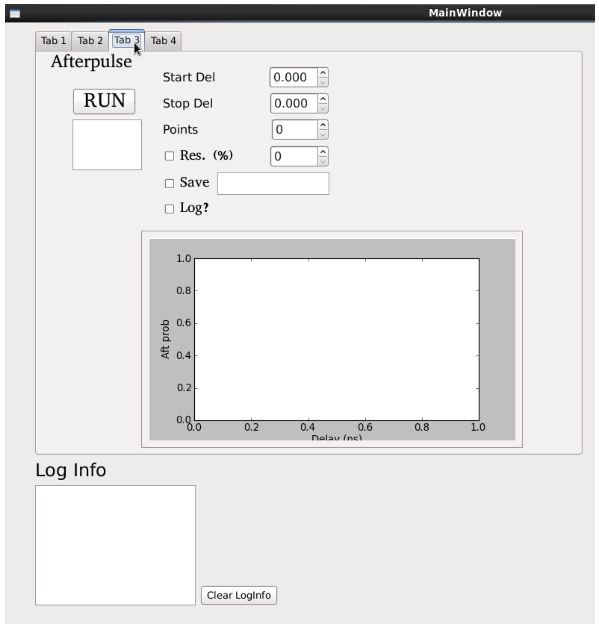

Figure 6: Tab 3 of main control program. Afterpulse characterization settings and results.

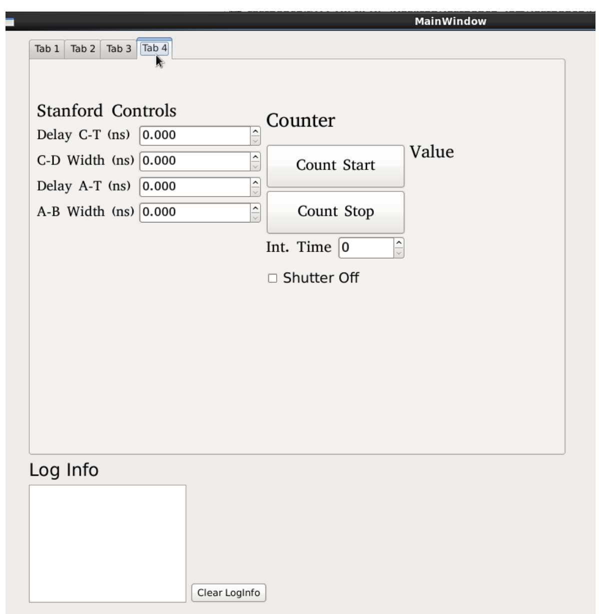

Figure 7: Tab 4 of main control program. Pulse generator settings and realtime external counter display.

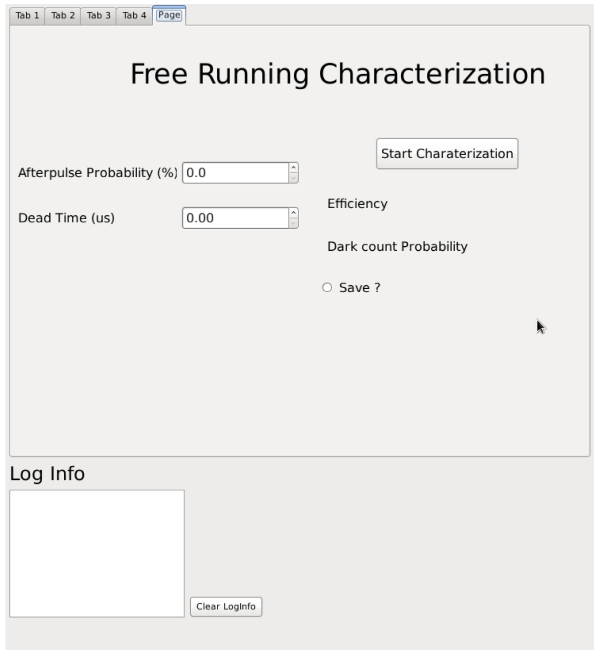

Figure 8: Tab 5 of main control program. Free-running characterization.

- Open the Terminal
  - *Applications > System Tools > Terminal*
- Change to correct directory:
  - Command: *cd Desktop/Testbench_Prog/v2.0*
- View files in directory:
  - Command: *ls*
- Select the latest version of the program and run it (xxxx_xx_xx corresponds to the program modification date):
  - Command: *python run_main_xxxx_xx_xx*

6 Gated detector

Gated setups

The test bench setup is shown in Figure 1. The whole system is synchronized from the Pulse Generator (SRS). This generates trigger pulses which control all of the instruments. The optical part of the system is triggered by the T_0 signal which activates the pulsed laser source. The optical signal is split at a coupler with one part going to a power meter, whilst the other is attenuated accordingly with a variable and a fixed attenuator, to achieve the required number of photons per pulse. The variable attenuator also has a shutter which is activated during dark count characterization.

During efficiency characterization and scanning of the gate shape, only the CD signal triggers the detector gate, the AB signal is set to zero. The delay between the T_0 and CD pulses must be synchronized such that the light pulse coincides with the correct point of the detector gate. The detector output is then counted with an external counter, as a coincidence with a delayed CD pulse.

Afterpulse characterization uses the double window method, hence both the AB and CD signals are used to trigger the detector. The laser pulse in this case is synchronized with the gate generated due to the AB pulse, whilst no light is sent onto the detector during the CD gate. Only the detections generated during the CD gate are registered by the external counter, hence by varying the delay between AB and CD it is possible to evaluate the afterpulse probability as a function of deadtime. In order to ensure that there is a detection in every AB window, the average photon number of photons per pulse is increased, to cause saturation.

6.1 Initialization

This section describes the procedure for the initialization of all of the test bench components. When characterizing a detector, it is preferable to carry out the tests in the order that they appear in this manual, since some of the values obtained in a given section are often required at a later stage for a different parameter characterization.

6.2 External Components

- Connect the output of the OR Port (Porte/OU) on the Electronic circuit rack to the external trigger input on the detector to be tested, using either the ECL or NIM signal appropriately, depending on the detector requirements.

- Connect the detector output to the Discriminator Analog Input on the Electronic circuit rack.

- Connect the output of the optical attenuator to the detector optical input.

- Power ON all of the remaining components in the following order:

  - Detector to be tested
  - Power meter/Attenuator

- Laser>. Turn the knob selector to *Petit pulse. WAIT ∼30 minutes to stabilize the laser outcoming power.*
- SRS Pulse Generator
- Agilent Counter
- Electronic component rack

- After the initial loading, the Power Meter/Attenuator meter display will remain in the terminal command view. Use it's dedicated keyboard (EXFO PMD Keyboard) to enter:
  - Command: *win*

  The windows display should now load on the screen.

6.3 Software

The following describes the initialization of the user interface software.

- Select path for attenuation log file. In Main Window:
  - Press: *Tab 1 > Connect*
  - Select *Data* folder and confirm

- Set the attenuator parameters. Remain in *Tab 1* (default values):
- Press: *Tab 1 > Choose input light.* The sub-tab shown in Fig.4 appears. *Laser Freq.*: Choose gating, then choose the laser frequency. Standard settings: Frequency: 10000
- *Ph. per pulse*: choose the desired number of photons per pulse. Standard settings: Photon /Pulse: 0.0. *To reduce the errors originated by multi-photon pulses is better to use small values of photons/pulse (between 0.1 and 0.5) for Efficiency and Gate Shape measurements.* For the afterpulsing characterization set 50.
- Press Ok.
- *Fix Att.*: -25.50 *This value is the value of the fixed attenuator just before the detector. It has been characterized but it fluctuates (∼ 10% of incertitude on the number of photons) every time that the attenuator is disconnected from the fiber. For more precise characterization we suggest to characterize this attenuator before to connect it to the detector.*
- Press *Attenuate*. The expected optical power value will be calculated and the attenuation procedure will begin. Optical power measurements will be logged in the graph. Wait until the power is stabilized (at least 5 consecutive points within a 0.05 dBm range).
- If any of the attenuator values need to be changed, *Stop attenuate* must first be pressed.

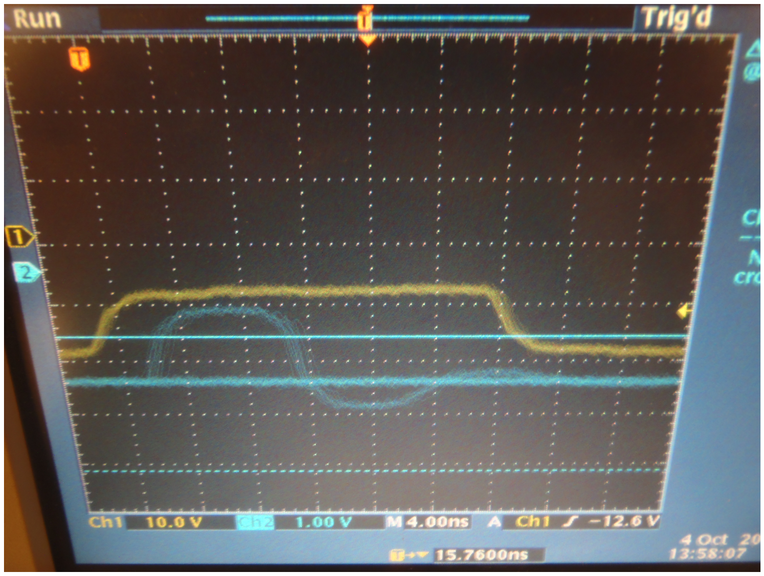

Figure 9: *CD* signal (yellow) and the detector output pulse (blue) viewed on an oscilloscope, showing the correct synchronization just before the coincidence port. Here the detector gate duration was 20 ns.

6.4 Circuit Delay Synchronization

This section deals with the unknown internal delay of the detector to be tested. In order to obtain meaningful results from the test bench it is important to match the unknown delay of the detector with the external manual delay on the test bench. The aim is have the detector output pulse rising edge within the CD pulse created by the SRS Pulse Generator. This will ensure that all of the detection counts are counted by the test bench. The easiest way to achieve this is to use an *Oscilloscope*, which is not necessarily stored on the test bench at all times.

- Disconnect the two inputs of the *Coincidence Port* on the Electronic circuit rack, one coming from the *Discriminator* and one from the *Manual Delay* module.
- *Important*: The signals to be viewed on the oscilloscope in the next step are ECL signals. To visualize these signals an offset blocks should be used, biased at -5.2 V.
- View the signals on the oscilloscope. Set the trigger on the CD pulse (coming from the manual delay).
- In *Tab 4*, complete the Stanford Controls (Pulse Generator) settings.
  - *Delay C-T*: 100 ns (arbitrary for the moment)

  - *C-D Width*: Set this to 5 ns **longer** than the gate time of the detector e.g. 25 ns for a detector with a gate duration setting of 20 ns.
  - *Delay A-T*: 0 ns
  - *A-B Width*: 0 ns

- The CD pulse should now be visible on the Oscilloscope. The detector output pulse may or may not be visible.

- Increase the Discriminator level until the detector output signal disappears, then decrease it by approximately 1.00 division beyond the level at which pulses appear.

- At the moment it is unlikely that the laser pulse is synchronized with the detector gate time. Hence the detection pulses visible are due to dark-counts. In order to find the "light":

  - You should look at the detection frequency, this could either be displayed on the detector itself, or you can use the frequency read out on the oscilloscope.
  - Increase the *Delay C-T* by 1 ns at a time (80ns is a good starting point) until the detection rate increases. This should also correspond to a more defined line on the oscilloscope.
  - Keep increasing the delay until the detection rate drops off once more, but note what was the highest detection rate achievable.
  - Now decrease the delay once more in order to set the **maximum** possible delay whilst having a detection rate value close to the highest achieved. This corresponds to the laser pulse coinciding with the start of the detector gate.

- Some detector pulses may occur at a later time, this is normal since a dark detection may occur at different times during the gate.

- At this point, you have to synchronize the signals coming at the inputs of the coincidence ports. To do that, you will probably have to change the settings on the manual delay (see below). **Before to change the settings on the manual delay, disconnect the CD line (Manual Delay) from the Oscilloscope: signal spikes from the module during switching may damage the Oscilloscope.** Change the Manual Delay settings so that the CD pulse begins at least 1 ns before the earliest rising edge of the detector output pulse. The traces should look as per Figure 9.

- The latest occurring rising edges of the detector output should be within the CD pulse. If not, adjust the *C-D Width* value accordingly. This will ensure that all of the detections within the detector gate are recorded by the test bench.

- Once the delays are synchronized, reconnect the two signal lines to the Coincidence Port on the Electronic Circuit rack.
- In MainWindow, *Tab 4*, select an *Integration Time* of 1 second and press *Count Start*.
- A count rate value should appear in the bottom right of the display. This value should be approximately equal to the count rate value on the detector display (if available). This indicates that the test bench is set up correctly.

7 Characterization Tests

7.1 Scan of the Gate

It is now possible to perform a scan of the gate. Doing this before measuring the detector efficiency is important in order to select the desired point on the gate (typically the middle) for the measurement.

- In *Tab 4*, select the integration time for each measurement (units of seconds). 1 second is sufficient for the initial scan of the gate.
- Select *Tab 2*. Complete the Scan Gate parameters:
  - *Start*: This should be in the region of the value of Delay C-T minus the C-D Width as set up in the previous section.
  - *End*: This should be higher than the Delay C-T set in the previous section.
  - *Points*: As required.
- It is possible to save the data by selecting the *Save* option and designating a file name. The file destination will be the *Data* folder as selected during the Connection procedure as described in Section 9.1.
- The gate scan will appear in the Main Window. Note that the scan is reversed in time in relation to the delay, hence the beginning of the gate corresponds to the longer delay values.

7.2 Detector Efficiency

It is possible to carry out a measurement of the detector efficiency at a determined position on the gate.

- In *Tab 4* select the required position on the gate with the *Delay C-T* value.
- Select the required *Integration Time*.
- In *Tab 2*, press *Meas Eff*. The resulting Efficiency and Dark Count Probability per gate will be calculated.

7.3 Afterpulse probability

In order to characterize the Afterpulse performance of the detector it is necessary to increase the optical power incident on the detector, in order to saturate detections to one every gate. The test bench uses the double window method for measuring the afterpulse probability.

- In *Tab 1* increase the number of photon number.
  - Press: *Stop Attenuate*.
  - Increase *Ph. per pulse* to 50.
  - Press: *Attenuate*.
  - Wait for the optical power to stabilize.
- In *Tab 4*:
  - Copy the *Delay C-T* value to *Delay A-T* field. This should be the value used during the efficiency measurement (Section 7.2), corresponding to the middle of the gate (or the optimum selected position).
  - Copy the *C-D Width* value to *A-B Width* field, from Section 7.2.
- In *Tab 3*, select the desired *Start*, *Stop* times and the number of *Points* for the afterpulsing scan.
- Press *Run* to begin the scan. The result will be displayed on the screen.
- The data can be saved using the *Save* option.

Free-Running detector

This section describes the procedure for the initialization of all of the test bench components to characterize a free-running detector. For this characterization it is important to know the afterpulsing probability and the dead time. Both can be measured or estimated. If estimated the precision depends on the esteem.

8 Free-running setups

The test bench setup is shown in Figure 2. The incoming light comes from a continuous laser. The optical signal is split at a coupler with one part going to a power meter, whilst the other is attenuated accordingly with a variable and a fixed attenuator, to achieve the required number of photons per second. The variable attenuator also has a shutter which is activated during dark count characterization.

During efficiency characterization the counter collects the detection rate with and without light, estimating the efficiency and the dark count rate including the saturation effects due to the dead time and the extra counts originated by afterpulsing.

9 External Components

- Connect the detector output to the Discriminator Analog Input on the Electronic circuit rack.
- Connect the output of the optical attenuator to the detector optical input.
- Power ON all of the remaining components in the following order:
  - Detector to be tested
  - Power meter/Attenuator
  - Laser>. Turn the knob selector to *Continuous. WAIT about 30 minutes the laser light to stabilize.*
  - SRS Pulse Generator(Required only to run the program)
  - Agilent Counter
- After the initial loading, the Power Meter/Attenuator meter display will remain in the terminal command view. Use it's dedicated keyboard (EXFO PMD Keyboard) to enter:
  - Command: *win*

  The windows display should now load on the screen.

9.1 Software

The following describes the initialization of the user interface software.

- Select path for attenuation log file. In Main Window:
  - Press: *Tab 1 > Connect*
  - Select *Data* folder and confirm
- Set the attenuator parameters. Remain in *Tab 1* (default values):
- Press: *Tab 1 > Choose input light*. The sub-tab shown in Fig.4 appears. Choose *Free-running*.
- *Photon/second*: choose the the desired number of photons per second. Standard settings: Photon /Second: 10000.
- Press Ok.
- *Fix Att.*: -25.50 *This value is the value of the fixed attenuator just before the detector. It has been characterized but its value fluctuates (∼ 10% of incertitude on the number of photons) every time that the attenuator is disconnected from the fiber. For more precise characterization we suggest to characterize this attenuator before to connect it to the detector.*

- Press *Attenuate*. The expected optical power value will be calculated and the attenuation procedure will begin. Optical power measurements will be logged in the graph. Wait until the power is stabilized (at least 5 consecutive points within a 0.05 dBm range).
- If any of the attenuator values need to be changed, *Stop attenuate* must first be pressed.

10 Characterization Tests

10.1 Efficiency and dark count characterization

It is now possible to characterize the efficiency and the dark-count probability.

- In *Page*, introduce dead time, τ, (in microseconds) and afterpulse probability (in percent), p_{ap}.
- In MainWindow, *Tab 4*, select the *Integration Time*. Use longer integration time for smaller errors. The correct value of integration time allows counting of, at least, 1000 detections/noise.
- In MainWindow, *Tab Page*, press Start Characterization. The program measures first the dark-count rate, dcr then the detection rate, r. After the Efficiency value, η and the dark-count probability, dcp is calculated.
- It is possible to save the data by selecting the *Save* option. The file name is *FRcharacterizationx_x_x_x_x.txt* where the x corresponds to the date at the moment of saving. The results will be saved in the same folder of the main program.

Formulas

- To calculate the dark count probability (corrected for the dead time), dcr^*, in FR mode:

$$dcr^* = \frac{dcr}{1 - dcr\tau} \tag{1}$$

- To calculate the efficiency (corrected for the dead time and afterpulsing)

$$\eta = \frac{1}{n}\left(\frac{r}{1 - r\tau} - dcr^*\right) \cdot \frac{1}{1 + p_{ap}} \tag{2}$$

where n is the average number of photons per second.