FASTER SAMPLER MnM USER MANUAL

The SAMPLER MnM (**M**easurement **n**umerical **M**odule) is a module designed for experimenters who want to imagine their own signal processing. It provides electronic signal frames with a maximum duration of 1428 ns, sampling the signal every 2 ns.

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Summary

I Theory of operation

The MnM SAMPLER provides “oscilloscope" frames of the electronic pulses detected by the MnM Trigger module of the MnM. For a better detection of these pulses, the raw signal can be filtered, its baseline reset. The experimenter then has the choice between acquiring the raw signal from the digitization of the signals by the CARAS daughter board, or the filtered signal used to detect the pulse.

There are two modes of operation, as shown on Figure 1:

- either the user acquires the samples on a fixed gate around the pulse,
- or on an automatic gate that adapts to the time width of the pulse, increased by a fixed gate before and after it. Nevertheless the gate cannot exceed 1428 ns.

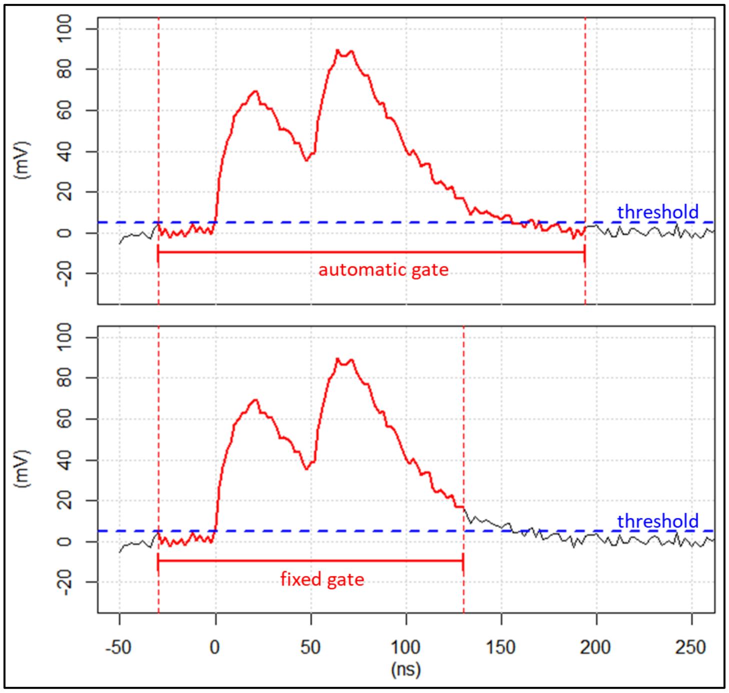


Figure 1: Example of automatic gate mode and fixed gate mode

As fixed gate can add dead time, three data output modules work in parallel. This reduces the loss of detected pulses, as shown in the Figure 2 below. If the first output is busy, in turn the second output is able to send a frame, then the third. There is a risk of data loss, if all 3 outputs are busy at the same time.

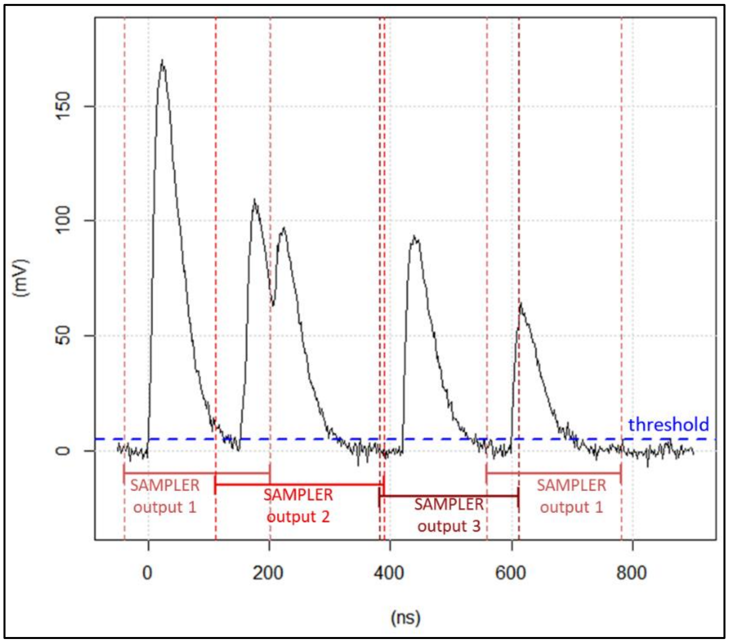


Figure 2: Three data output module work in parallel.

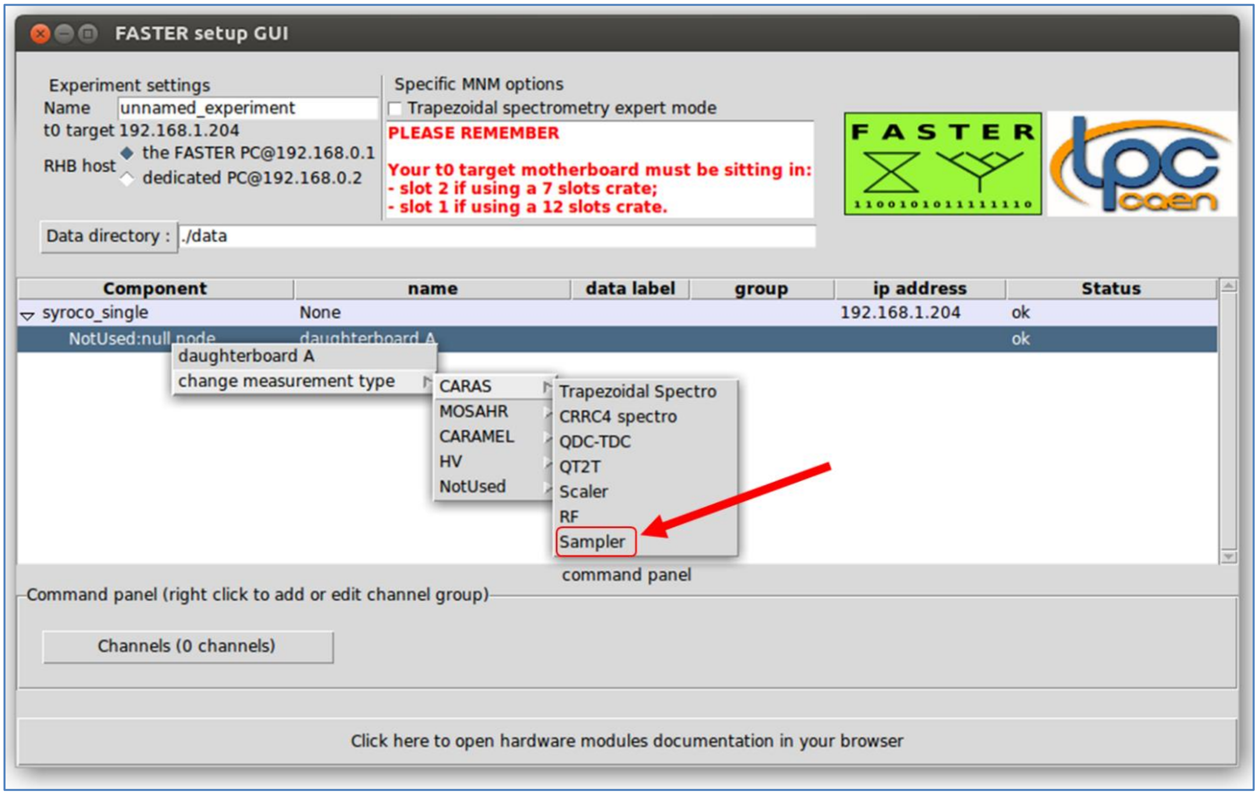
A SAMPLER frame always has an even number of samples. The time step between 2 samples is 2 ns.

II Preamble

II.A FASTER launching

To take benefit of the SAMPLER MnM of the FASTER acquisition, the experimenter can build his experiment interface with the command `faster_setup_gui`.

The interface, shown on Figure 3, is launched. To use the FASTER SAMPLER MnM, the experimenter must select the “SAMPLER” type, by right-clicking on the daughterboard line.



Name: unnamed_experiment
t0 target: 192.168.1.204
RHB host:
● the FASTER PC@192.168.0.1
○ dedicated PC@192.168.0.2

PLEASE REMEMBER

Your t0 target motherboard must be sitting in:
- slot 2 if using a 7 slots crate;
- slot 1 if using a 12 slots crate.

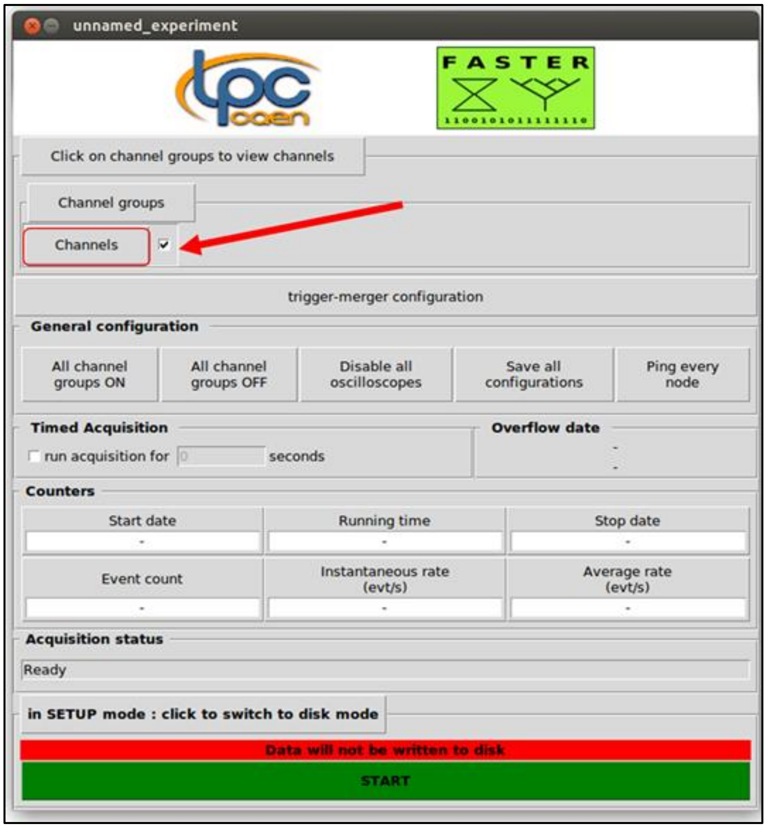
Data directory : ./data

Component	name	data label	group	ip address	Status
syroco_single	None			192.168.1.204	ok
NotUsed:null node	daughterboard A				ok

Figure 3: experiment building with “faster_setup_gui”.

Before exiting the application form, the user can choose the names of the experiment, of the daughterboard and of each channel of the “daughterboard”.

With the command line `faster_gui`, the experimenter accesses to the FASTER acquisition display, shown on Figure 4.



Channels ☑

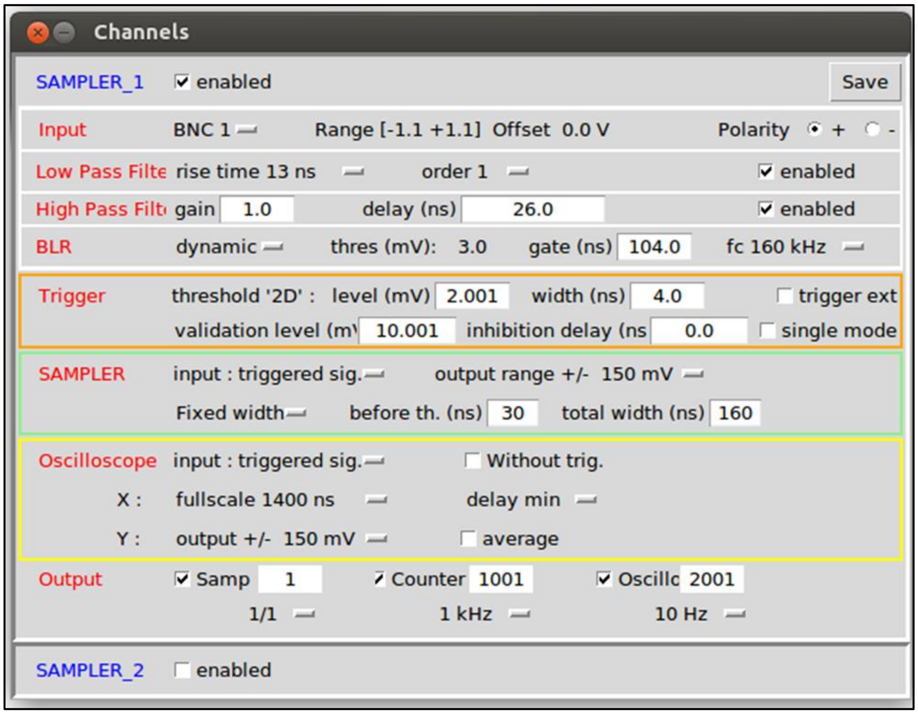
☐ run acquisition for 0 seconds

Acquisition status: Ready

Data will not be written to disk

Figure 4: faster_gui interface.

By clicking on "Channels" (cf. Figure 4), the MnM interface is displayed, allowing the user to adjust the different module parameters (Figure 5).



SAMPLER_1 ☑ enabled

Input BNC 1 Range [-1.1 +1.1] Offset 0.0 V Polarity ● + ○ -

Low Pass Filte rise time 13 ns order 1 ☑ enabled

High Pass Filt gain 1.0 delay (ns) 26.0 ☑ enabled

BLR dynamic thres (mV): 3.0 gate (ns) 104.0 fc 160 kHz

Trigger threshold '2D' : level (mV) 2.001 width (ns) 4.0 ☐ trigger ext
validation level (m\ 10.001 inhibition delay (ns 0.0 ☐ single mode

SAMPLER input : triggered sig. output range +/- 150 mV
Fixed width before th. (ns) 30 total width (ns) 160

Oscilloscope input : triggered sig. ☐ Without trig.
X : fullscale 1400 ns delay min
Y : output +/- 150 mV ☐ average

Output ☑ Samp 1 ☑ Counter 1001 ☑ Oscillc 2001
1/1 1 kHz 10 Hz

SAMPLER_2 ☐ enabled

Figure 5: SAMPLER interface

II.B RHB launching

To take benefit of RHB displays, the experimenter shall execute the command `faster_rhb_demo_sampler_copy` in the working directory, in order to have an example of RHB files adapted to the FASTER SAMPLER MnM.

A new repertory `SAMPLER_RHB_Demo` is created. The user shall go in the Discri repertory contained in the repertory `SAMPLER_RHB_Demo`, before launching RHB interface.

```
cd SAMPLER_RHB_Demo
cd Discri
RHB -r
```

III Description of FASTER SAMPLER MnM

The interface includes several tuning modules, synthetically described in Table 1 and Figure 6. Each module has some parameters that are adjustable by the user to achieve the best performance.

module	**Border color**	**Purpose**
Input module	white	It defines the dynamic range, the polarity of the input signal, and provides filters to clean it.
Trigger module	orange	It timestamps the particle arrival time and wakes up the other modules except BLR module.
SAMPLER module	green	It allows the user to define the characteristics of SAMPLER output frame (gate, Y-scale).
Oscilloscope module	yellow	It allows the user to visualize several module signals
Data output module	no color	It allows the user to choose output data (label, rate)

Table 1: Description of the SAMPLER MnM

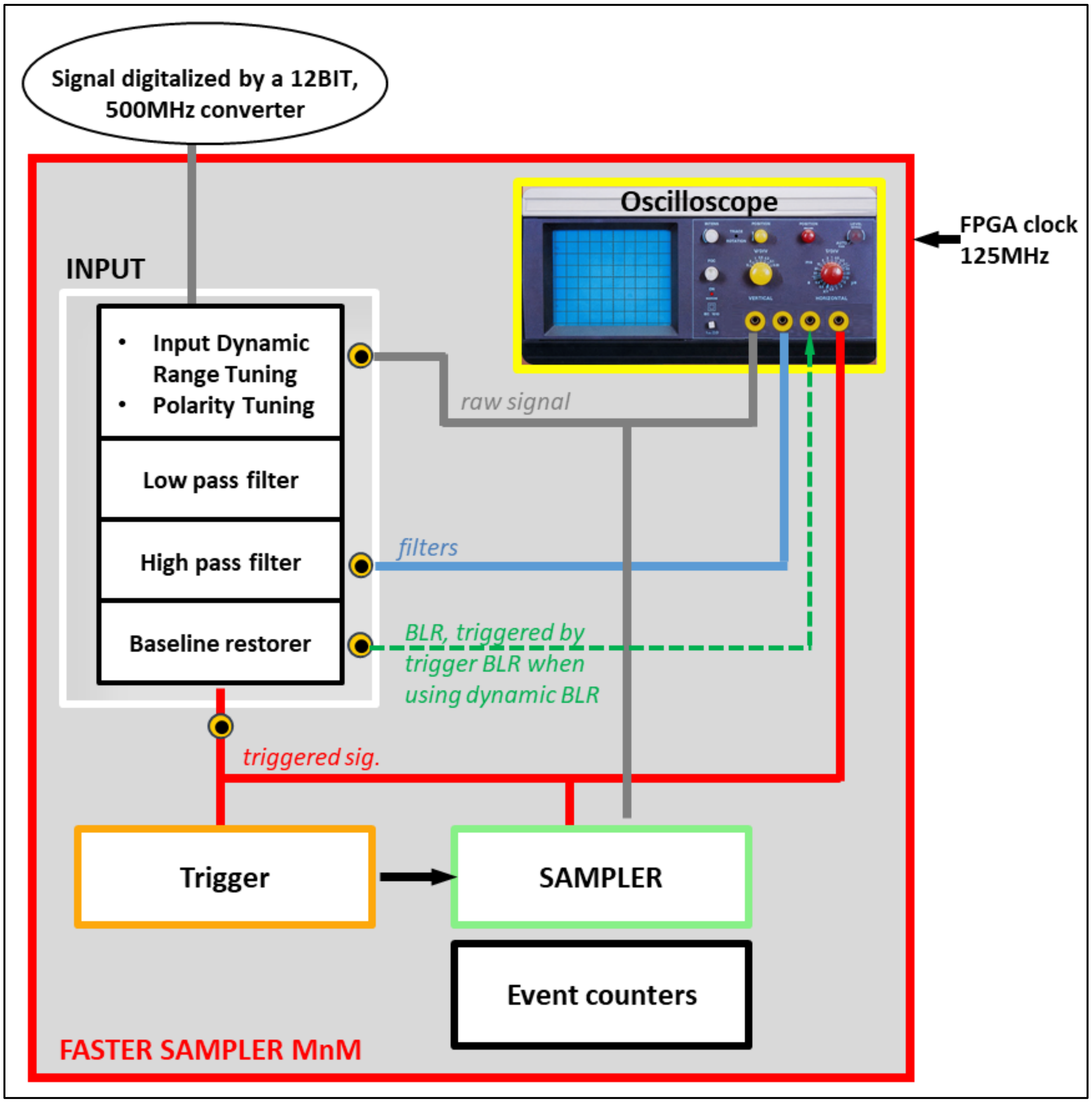


Figure 6: Diagram of FASTER SAMPLER MnM. The border colour of each box is as the one of the MnM interface.

The following chapters describe these different modules and explain how to select all the FASTER SAMPLER MnM parameters to acquire the best sample data. We recommend to use RHB facilities to display data. The signal shapes are observable thanks to the Oscilloscope module. This one is therefore the first to be described.

III.A The Oscilloscope module

The signal, which is displayed by the oscilloscope module, is defined by parameter ① (Figure 7). Each ◉ on Figure 6 indicates the location of an Oscilloscope module input. The use case of this signal is described in Table 2.

Input signal	**Use case**
raw signal	To adjust Raw signal module parameters
filters	To adjust filters parameters before BLR
BLR	To adjust BLR module parameters
triggered sig.	To adjust trigger module parameters.

Table 2: Use case of the Input signal of the Oscilloscope module

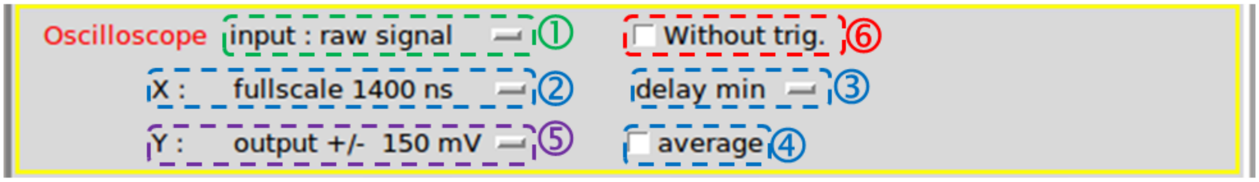


Figure 7: Oscilloscope module.

The user can select the time fullscale range with parameter ②. Oscilloscope data contains up to 700 points separated by a time step. As the time step is a power of 2 ns, the proposed dynamic ranges vary from 1400 ns to 5.2 µs.

As each ion-induced pulse, triggered by the Trigger module or the BLR Trigger module, is identified by the relative time "0 ns" in an oscilloscope frame, the user can select where to place the sample "0 ns" ("min", "25%", "50%", "75%"), with the shift parameter ③.

If the “AVERAGE” button ④ is checked, every sample of the oscilloscope display is the average of many samples (2 for 2800 ns range, 4 for 5600 ns range, 8 for 11 µs range …). Therefore, oscilloscope display seems to be less noisy than it is in reality. When “AVERAGE” is unchecked, one sample every 2 or 4 or 8 or 16 (etc.), depending on time-range value of 2800 ns, 32 ns, 5600 ns or 11 µs (etc…) forms the oscilloscope display. The sample, which triggered the Trigger module, is not necessarily apparent.

The Y-fullscale ⑤ depends on CARAS daughter board characteristics. It is always 0 centered, and the experimenter can zoom the signal display between +/- 150 mV, +/- 300 mV, +/- 600 mV, +/- 1200 mV or +/- 2400 mV.

If “without trig” is checked in ⑥ (Figure 7), Oscilloscope module does not use the Trigger module or BLR Trigger to start storing an oscilloscope frame, but it uses a clock, whose frequency is defined in the “Data output” module (cf. Figure 8).

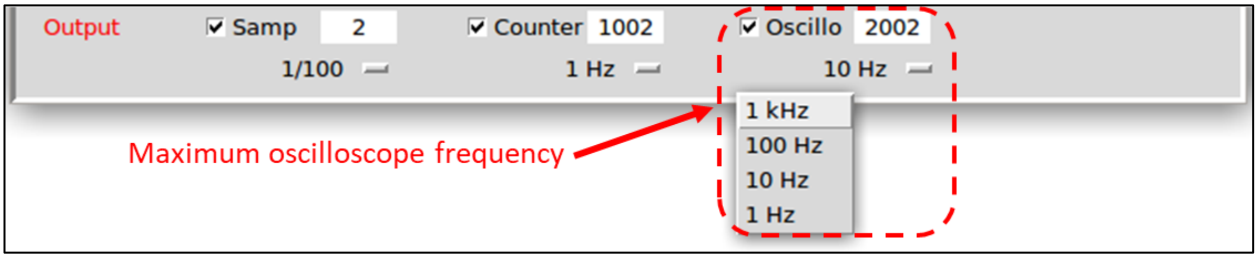


Figure 8: Maximum frequency of the oscilloscope frame definition

If “without trig” is unchecked in ⑥ (Figure 7), the Oscilloscope module is woken either by the BLR trigger if the displayed signal is “trigger BLR”, otherwise by the Trigger module. In all case, the maximum oscilloscope frequency is defined by the Data output module.

III.B The Input module

In this module, the user has to define the raw signal (cf. Figure 9). That means:

- its link with one of the two daughter board input channel ①,
- its ranges ②,
- its polarity③.

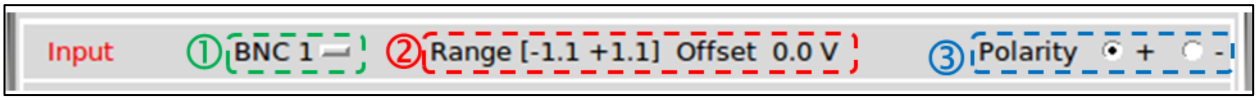


Figure 9: The raw signal parameters.

III.B.1 The CARAS Data Channel Selection

The CARAS daughter board has two input channel called SMB 1 and SMB 2. Each FASTER SAMPLER MnM in the FPGA can be linked with any SMB, as shown Figure 10 and Figure 11.

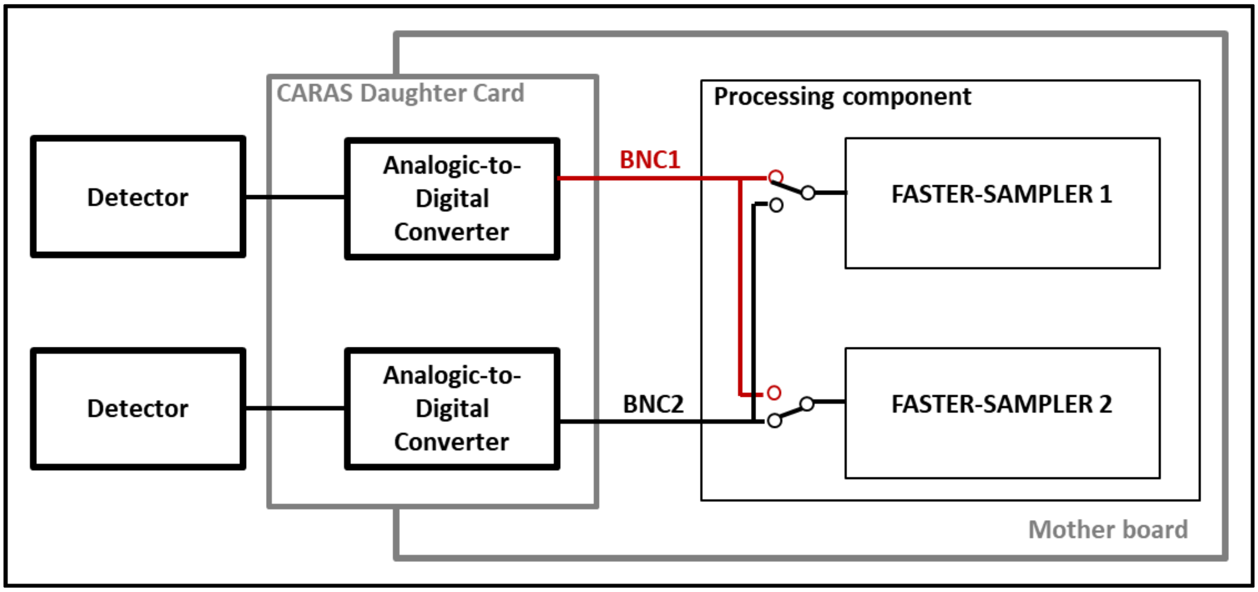


Figure 10: Multiplexers to select which analog channel to be processed.

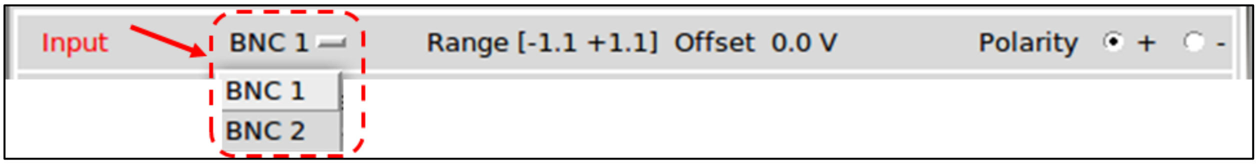
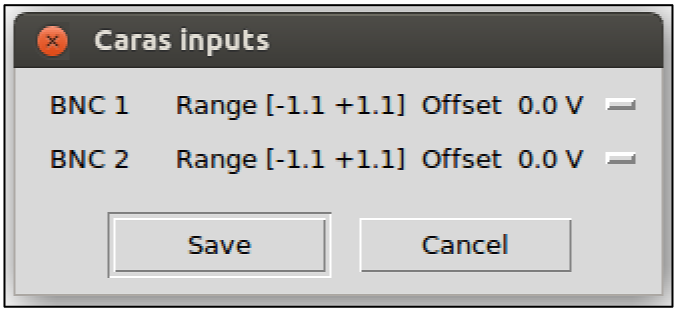


Figure 11: Input Channel selection.

III.B.2 Range Tuning

Each SMB channel can have a different dynamic input range from [0.0 +2.2] V to [-2.2 0.0] V. This dynamic range is configured by the user, by clicking on “Range” switch ② Figure 9. A new interface is launched (cf. Figure 12): the user can add a voltage source (called “Offset”) between -1.1 V and 1.1 V with 0.1 V-step.



Caras inputs

BNC 1 Range [-1.1 +1.1] Offset 0.0 V

BNC 2 Range [-1.1 +1.1] Offset 0.0 V

Figure 12: fullscale range interface for CARAS daughter board.

III.B.3 Polarity Tuning

The Oscilloscope module allows the user to display the raw signal (Figure 13):

The FASTER-SAMPLER process uses positive values. If the detector provides a negative signal, it is essential to convert it into a positive signal, with selection check button ③ (Figure 9).

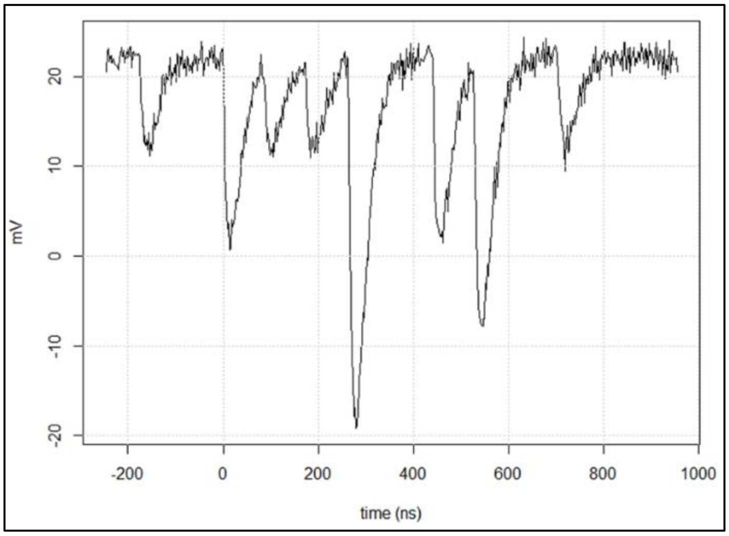


Figure 13: Raw signal example. As the pulse direction is downward, the polarity ”-“ must be selected.

III.C The low-pass filter module

If the experimenter wants to benefit from a low-pass filter, he must check the "enable" box ① (Figure 14).

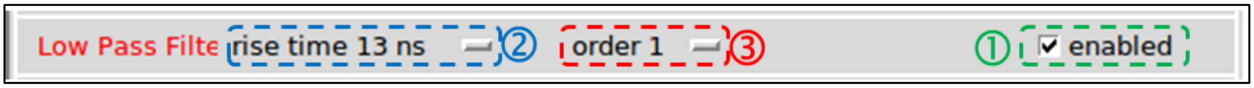

Low Pass Filte rise time 13 ns ② order 1 ③ ① ☑ enabled

Figure 14: Low-pass filter parameters.

The user can select with button ② (Figure 14) one of the four available filters: either he chooses a moving average of 4 samples, or he chooses a filter defined by its rise time: 13 ns, 27 ns or 57 ns.

He can select the filtering order ③ (Figure 14) : “order 1” means that there is only one low-pass filter, “order 2” means that there are two successive low-pass filters, “order 3” means that there are three successive low-pass filters. Figure 15 shows the different effects of low-pass filters on one electronic pulse.

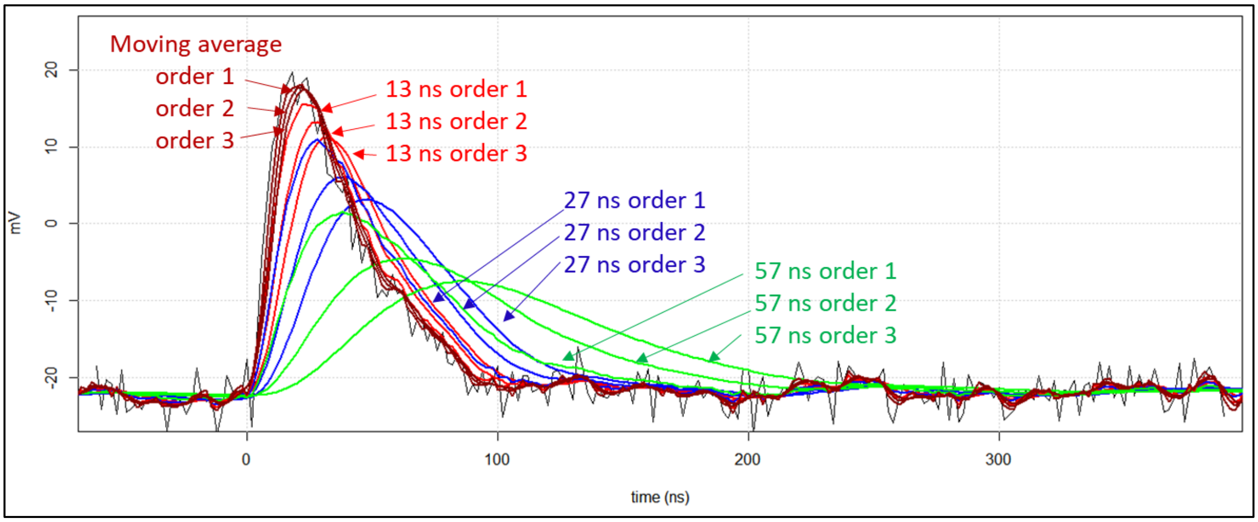


Figure 15: effects of different low-pass filters

III.D The High-pass filter module

If the experimenter wants to benefit from a high-pass filter, he must check the "enable" box ① (Figure 16).

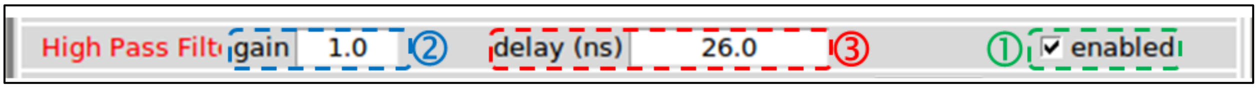

High Pass Filt gain 1.0 ② delay (ns) 26.0 ③ ① ☑ enabled

Figure 16: High-pass filter parameters

This high-pass filter is a delay-line pass-filter. The experimenter has to tune the gain from 0 to 1 ② (Figure 16), and the delay from 2 ns to 56 ns ③ (Figure 16).

The implemented operation is:

$$S_{out}(t) = S_{in}(t) - gain \cdot S_{in}(t - delay)$$

If the gain is equal to 1, the resulting signal is bipolar, with a baseline centered on zero, as shown on Figure 17.

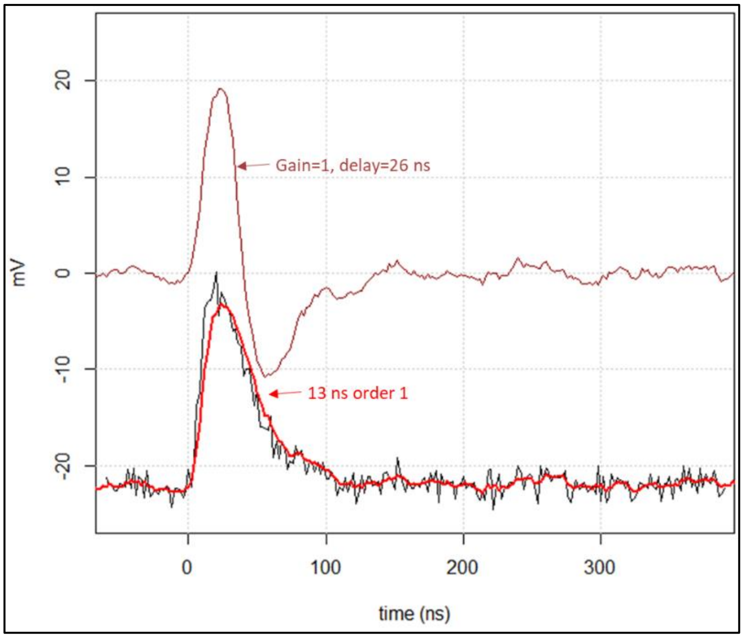


Figure 17: Effect of the delay-line high-pass filter (gain=1, delay=26 ns) located after a low-pass filter (t_{rise}=13 ns, order 1)

III.E Baseline Restorer Filter module

The role of the BLR module is to put the baseline at 0 mV. The BLR module operates on the filtered signal if filters are enabled. The user can choose between two kinds of baseline restorer: a constant one and a dynamic one.

III.E.1 Constant BLR

level (mV): -22.0

Figure 18: Constant BLR level

This constant BLR simply subtracts a constant level.

III.E.2 Dynamic BLR

Figure 19 explains the dynamic BLR concept. The dynamic BLR filter follows the slow variations of the baseline as long as it does not detect an event. If it detects one, it maintains the last constant level during all the event duration. The resulting signal is therefore the baseline, which is then subtracted from the input signal.

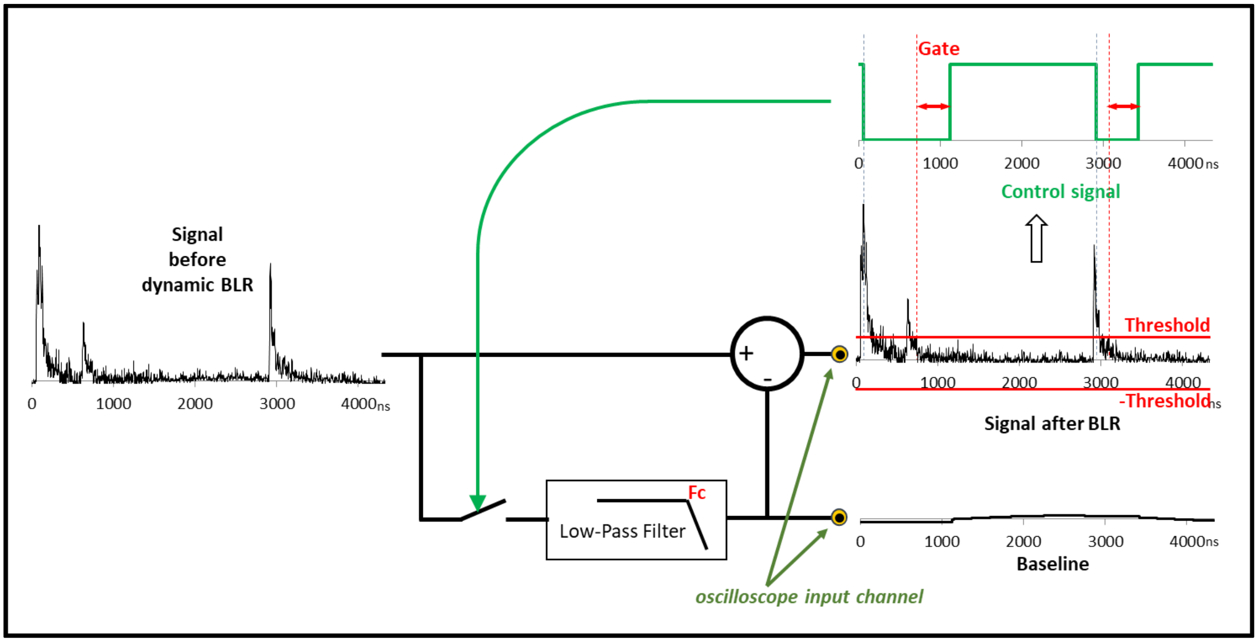


Figure 19: BLR concept

The signal from the previous filter module is filtered by a new low-pass filter. This tracking filter lets through any slow variations of the signal. The **cut-off frequency "fc"** ① (Figure 20) of this low-pass filter is 20 kHz, 160 kHz, 640 kHz or 6600 kHz. It is a first order low-pass filter.

The baseline tracking by the low-pass filter is stopped when an event is detected. That means when the cleaned **signal after BLR exceeds a "± threshold" parameter value** ②(Figure 20). Then the baseline tracking stops while the value of signal samples is above the threshold and after a **duration defined in the "gate" parameter** ③(Figure 20). Thus, the signal tracking is stopped during all the signal duration. When the baseline tracking is stopped, the computed baseline value is set to the baseline value just before the detected event. In case of pile up, the computed baseline value is equal to the baseline value just before the first detected event.

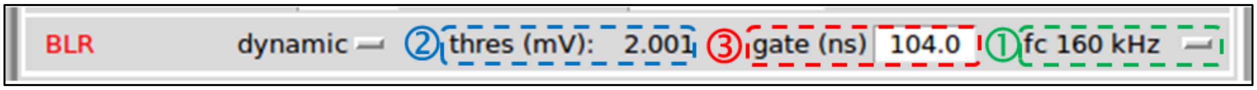

BLR dynamic ② thres (mV): 2.001 ③ gate (ns) 104.0 ① fc 160 kHz

Figure 20: Dynamic BLR parameters.

To adjust BLR threshold, the experimenter must display **"Input: BLR"** with the Oscilloscope module. It is very important that the BLR adjustment is minutely performed by observing this oscilloscope display:

- The BLR threshold should be as small as possible, and selected just above the electronic noise. If this threshold level is too low, the BLR will never have the opportunity to follow the baseline. If it is too high, it will take physical events as baseline disturbances.
- "gate" values duration, where tracking is disabled, must be large enough to encompass the entire input signal of the BLR.
- The low-pass filter frequency Fc is preferentially chosen at 20 kHz, in order to improve the signal-to-noise ratio. If pulses rate is high, this frequency must be increased.

III.F The Trigger module

III.F.1 External/Internal trigger

There are two SAMPLER MnMs implemented in one FPGA on the mother card. Each MnM has an internal trigger, but a MnM can use the trigger of the adjacent MnM (cf. Figure 21) by checking "trigger ext" (cf. Figure 22).

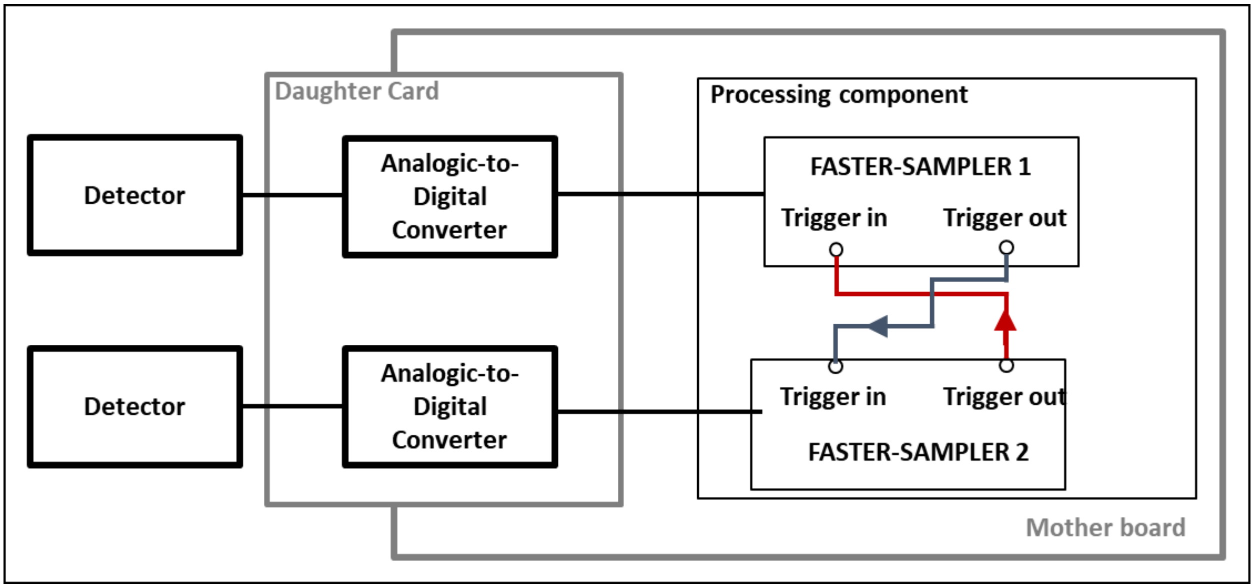


Figure 21: Crossed trigger diagram.

Trigger

threshold '2D' : level (mV) 2.001 width (ns) 2.0 ☑ trigger ext

validation level (m 2.001 inhibition delay (ns 0.0 ☐ single mode

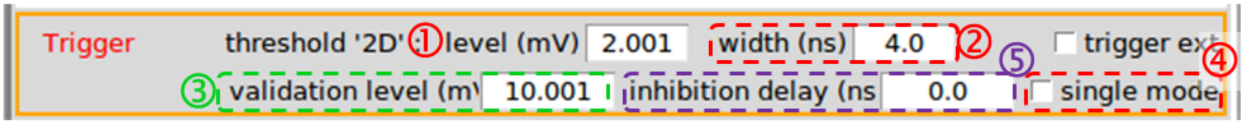
Figure 22: Check "trigger ext" to use external trigger.

The external trigger is only available if the experimenter has selected a fixed gate in the SAMPLER module (cf. §III.G.3 p18).

III.F.2 Internal trigger

If "trigger ext" is not checked, the MnM detects signal pulses with its own trigger module. This one module has a threshold discriminator. The detected event is timestamped with a 2 ns accuracy clock. To adjust Trigger module parameters, the experimenter must display **"Input: triggered sig."** with the Oscilloscope module.

All input pulses of the Trigger module, whose signal has crossed the threshold "Level" (Figure 23 ①) on rising edge and remains above this level during at least the duration "width" (Figure 23 ②), are detected. But only pulses with an amplitude over the "validation level" in (Figure 23 ③) during the first 64 nanoseconds are retained.



Trigger threshold '2D' ① level (mV) 2.001 width (ns) 4.0 ② ⑤ ☐ trigger ext ④

③ validation level (m\ 10.001 inhibition delay (ns 0.0 ☐ single mode

Figure 23: parameters of the threshold discriminator.

On Figure 24, we can see that a judicious value of “width” parameter can discriminate physical event from noise. “width” parameter is a multiple of 2 ns, between 2 ns and 64 ns. When displaying the “triggered sig.” signal with an 2 ns step, the sample at time “0 ns” is the first sample above the threshold level.

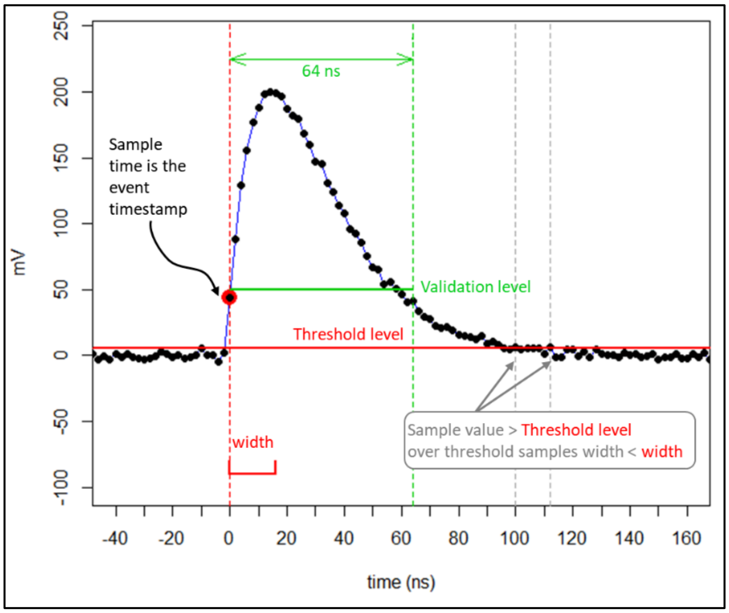
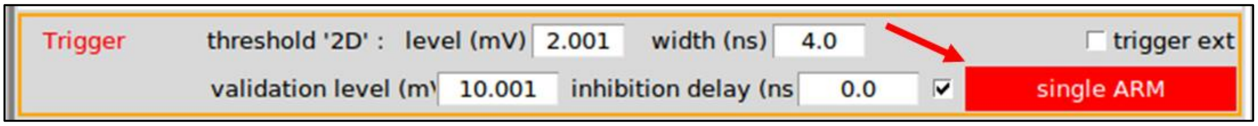


Figure 24: The first pulse, which has crossed the threshold level is detected. The following ones are not, thanks to a judicious value of the “width” parameter.

By checking “Single mode” (Figure 23 ④), the “Single Arm” button appears (Figure 25). A cursor click on this button will trigger a single pulse detection.



Trigger threshold '2D' : level (mV) 2.001 width (ns) 4.0 ☐ trigger ext

validation level (m\ 10.001 inhibition delay (ns 0.0 ☑ single ARM

Figure 25: "Single Arm" button

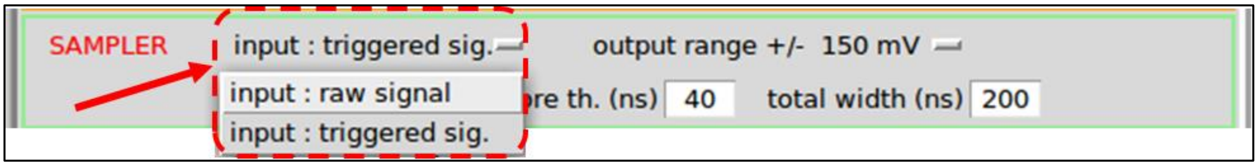
Finally, the experimenter can adjust the minimum duration between two detections with the “Inhibition delay” parameter (Figure 23 ④), in order to ensure dead time duration. This duration must be wider than the pulse width, otherwise it has no impact. It is a multiple of 8 ns between 0 ns and 17 s.

III.G SAMPLER

The “SAMPLER” module is used to define the different characteristics of SAMPLER output data.

III.G.1 Acquired Signal

The experimenter chooses first signal he wants to acquire: either the “raw signal” digitized by the CARAS digitizer, or the “triggered signal” that is used by the MnM Trigger module, as shown on Figure 26.



output range +/- 150 mV

re th. (ns) 40

total width (ns) 200

Figure 26: Definition of acquired signal.

III.G.2 Output data range

The user selects then the output data resolution. SAMPLER output data is a 16-BITS signed integer. This 16 BIT can be distributed on (cf. Figure 27):

- About ±2390 V: “output range +/-2400mV”
- About ±2390/2 V: “output range +/-1200mV”
- About ±2390/4 V: “output range +/-600mV”
- About ±2390/8 V: “output range +/-300mV”
- About ±2390/16 V: “output range +/-150mV”

All out-of-range data is coded to the limit values of the range

input : triggered sig.

output range +/- 150 mV

Fixed width

before t

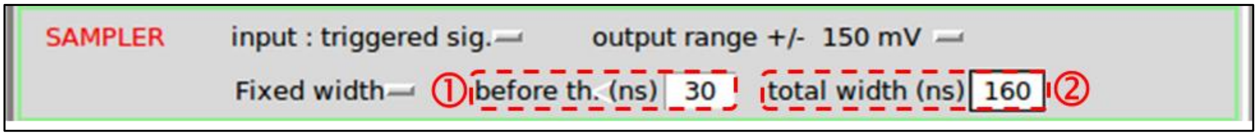
200

Figure 27: SAMPLER output data range.

III.G.3 Data gate

As explained in chapter I p4, there are two types of gates configured around a pulse: either a gate with a fixed width or a gate with an automatic width.

III.G.3.a Fixed width



input : triggered sig.

output range +/- 150 mV

Fixed width

before th. (ns) 30

total width (ns) 160

Figure 28: “Fixed width” parameters interface.

In “Fixed width” mode, the user chooses the duration between 0 ns and 80 ns (Figure 28 ①) he wants to acquire before the first sample of the pulse above the trigger threshold (cf. Figure 29).

He also selects the total duration of the frame he wants to acquire (Figure 28 ②). This duration may not exceed 1428 ns. It must be a multiple of 4 ns, because the number of samples in the SAMPLER output data must be even and the sampling step is 2 ns.

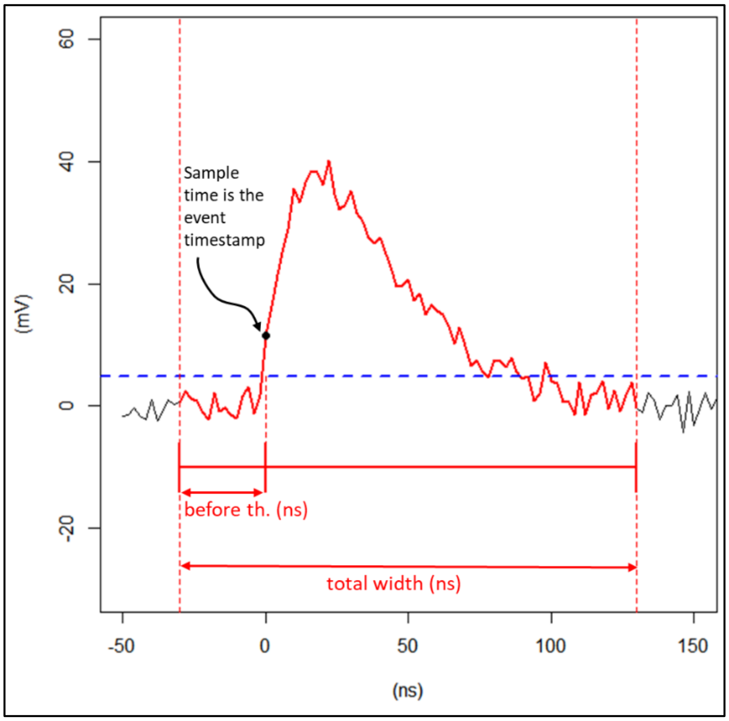
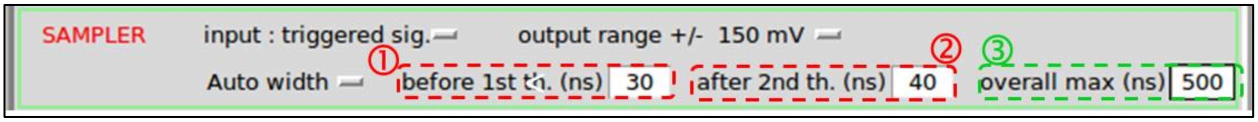


Figure 29: Parameters of "fFxed width" mode

III.G.3.b *Automatic width*

In automatic mode, the number of samples acquired adjusts to the pulse duration. The SAMPLER frame includes all samples whose value is over the trigger threshold, in addition to a duration before the first sample (“before 1st th. (ns)”, Figure 30 ①) and a duration after the last sample (“after 2nd th. (ns)”, Figure 30 ②). If the number of samples in the frame is odd, the sum of these three durations is increased by 2 ns.

Since the pulse duration is expandable, especially if there is piled-up, a maximum gate duration, called “overall max (ns)” (Figure 30 ③), must be set, which must not be exceeded. This value is less than or equal to 1428 ns.



SAMPLER input : triggered sig. output range +/- 150 mV

Auto width ① before 1st th. (ns) 30 ② after 2nd th. (ns) 40 ③ overall max (ns) 500

Figure 30: “Auto width” parameters interface.

Figure 31 shows all the definitions of these parameters.

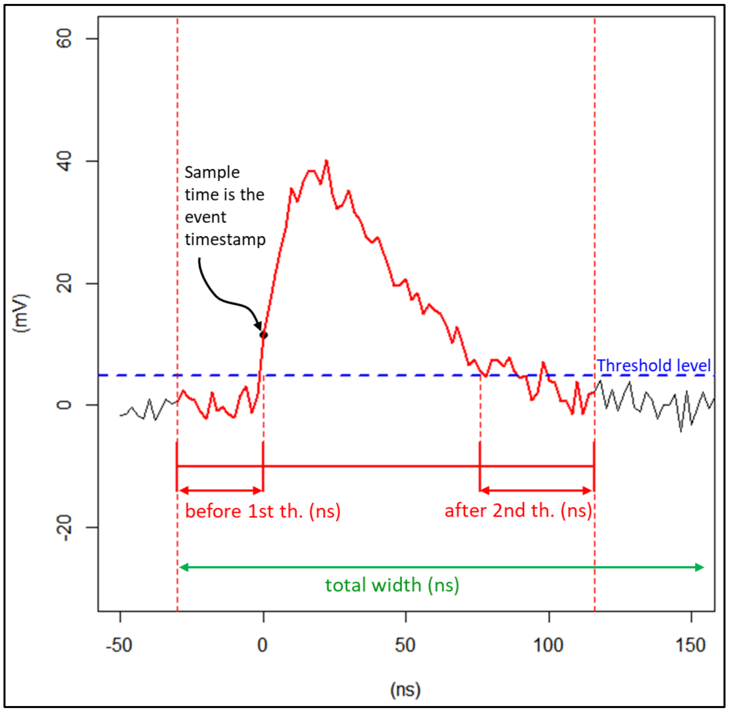


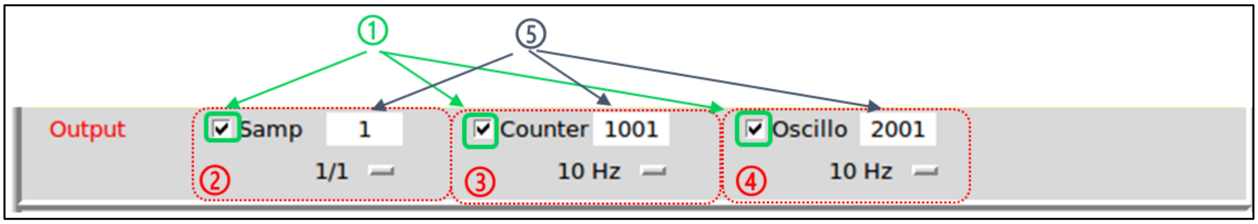
Figure 31: Parameters of "Auto width" mode

III.H Data output module

The Data output module (Figure 32) defines the output data sent to the computer by checking buttons ①. These data are:

- the data processed by the SAMPLER module ②,
- the counting data ③,
- the data from the Oscilloscope module ④.

To distinguish these data in the stored file, they have different labels ⑤. The user can moreover control the rate of output data.



☑ Samp 1
1/1

☑ Counter 1001
10 Hz

☑ Oscillo 2001
10 Hz

Figure 32: parameters of the Data output module

When the data comes out the FASTER SAMPLER MnM, they are temporally stored in some buffers of the FPGA, waiting for being sent to the computer by the Gigabit Ethernet communication.

Here are described the content of each data. If the experimenter uses RHB facilities, data from FASTER SAMPLER MnM are called SAMPLER in the RHB file ”*.pid“. In this file, the prefix label of each channel of the FASTER acquisition is defined. For example, if there is

1: SAMPLER: myChannel

that means that all data from the first channel of FASTER acquisition must have the prefix “**myChannel_**” in the configuration file of RHB (i.e. “*.facqConf” file). The “RHB –r” command, made in the directory including these files, starts RHB interface.

III.H.1 “SAMPLER” data

The experimenter can store or display all “SAMPLER” data processed by the SAMPLER module by enabling data output (cf. Figure 33 ①) and selecting 1/1 (cf. Figure 33 ②). But, when the event rate is too high and saturates the FASTER acquisition, the user can choose to store a percentage of this rate: one event data every 100 event data is sent, or every 10^4 event data, or one event data every 10^5 event data. With this decimation parameter, the acquisition efficiency can be controlled.

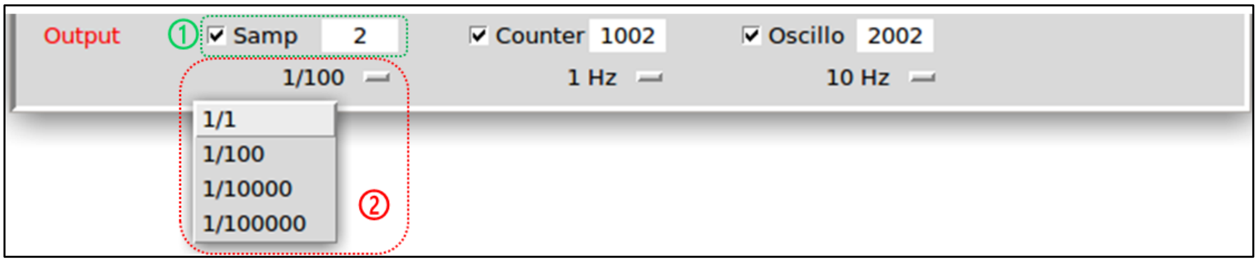


Figure 33: decimation of "Scaler" data

In “SAMPLER” data, the user has, for each event, the following information:

- **myChannel_SAMPLES**: this is the samples waited by the user. Each sample is a 16-BIT signed integer. For information only, if output range is
  - +/-150mV, the value of a sample in millivolt is about: $\mathrm{SAMPLES} \cdot \frac{2390}{2^{19}}\ (mV)$
  - +/-300mV, the value of a sample in millivolt is about: $\mathrm{SAMPLES} \cdot \frac{2390}{2^{18}}\ (mV)$
  - +/-600mV, the value of a sample in millivolt is about: $\mathrm{SAMPLES} \cdot \frac{2390}{2^{17}}\ (mV)$
  - +/-1200mV, the value of a sample in millivolt is about: $\mathrm{SAMPLES} \cdot \frac{2390}{2^{16}}\ (mV)$
  - +/-2400mV, the value of a sample in millivolt is about: $\mathrm{SAMPLES} \cdot \frac{2390}{2^{15}}\ (mV)$
- **myChannel_t**: the time-stamp (in nanosecond) of the event, with a 2 ns accuracy.

III.H.2 “Counters” data

By enabling the “Counters” output (cf. Figure 34 ①), the experimenter can store and display the counting data, called “Counters” with a selected frequency of 1 Hz, 10 Hz, 100 Hz and 1 kHz (cf. Figure 34 ②).

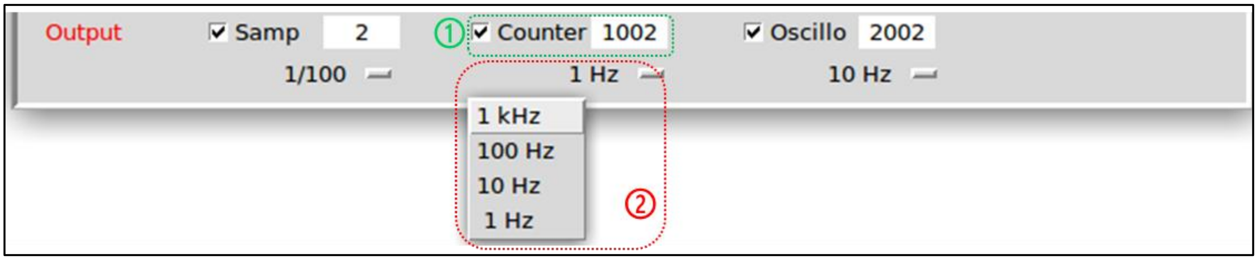

Output ☑ Samp 2 1/100 ☑ Counter 1002 1 Hz ☑ Oscillo 2002 10 Hz

Figure 34: out frequency of the "Counters" data

Each "Counters" data has:

- **myChannel_COUNT_t:** the time-stamp of the "Counters" data
- **myChannel_TRIG**: the number of events discriminated by the Trigger module of the MnM.
- **myChannel_CALC**: depends on the decimation parameter (cf. Figure 33). In case of "auto width" and null durations before and after pulse (cf. III.G.3.b)
$$\text{myChannel\_CALC} = \text{decimation} \cdot \text{myChannel\_TRIG}$$
- **myChannel_SENT**: the number of data from SAMPLER module, temporally stored in the FPGA buffers, and waiting for being sent to the computer.

The following inequality is always verified: myChannel_SENT≤ myChannel_CALC ≤ myChannel_TRIG.

These myChannel_TRIG, myChannel_CALC and myChannel_SENT are reset each time any module parameters is changing.

III.H.3 "Oscillo" data

The "Oscillo" data, already explained in chapter III.A , are defined in RHB by the variables:

- **myChannel_OSC_t**: the time stamp of the "0 ns" sample of the oscilloscope frame.
- **myChannel_OSC**: the Oscilloscope frame.