IDQ

SWISS QUANTUM

Redefining Measurement

Time Controller Series
User Manual

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1 About this manual

1.1 Message to the user

Congratulations on having purchased this ID Quantique measurement apparatus. The Time Controller Series integrates the long and renowned experience that ID Quantique has developed with single-photon systems and applications since the company's inception.

To get the most out of this equipment, we recommend that you read this manual carefully. This manual provides information about the equipment principle of operation as well the following guidance:

- How to safely install a Time Controller Series device
- How to prepare a Time Controller for time correlation measurements
- How to install and use the Time Controller software
- How to begin integrating the Time Controller into your lab's software environment

1.2 Getting support

Support for ID Quantique instrumentation is provided directly by ID Quantique SA and ID Quantique-authorized and trained technical personnel. To get support, contact ID Quantique by one of the following channels.

- E-mail: support@idquantique.com
- Phone: +41 22 301 83 71 (Monday to Friday, from 9 am to 5 pm GMT+1)
- Check our website for more information on ID Quantique locations: https://www.idquantique.com/about-idq/contact-us/

To facilitate the user support, be ready to provide the model and version of the Time Controller Series device you are using. In case of bugs please write down the error message and the situation in which it has occurred as well as the software version.

1.3 Conventions used in this manual

The following conventions are used in this manual, where an icon to the left of text warns that an important point must be observed:

Note: denotes a note which alerts you to important information

Caution: action may cause damage to the device

Warning: action may cause harm to the user

1.4 Disclaimer

Though the information in this document is believed to be correct at the time of publication, ID Quantique is not liable for any direct, indirect, special, incidental, or consequential damages resulting from inaccuracies or omissions in this document. ID Quantique may make changes to this document—as well as designs, specifications, and descriptions of related products—at any time without prior notice. ID Quantique disclaims all liability, including liability for infringement of any proprietary rights, relating to use of information in this document.

1.5 Warranty

ID Quantique guarantees this equipment against defect in material and workmanship, to meet applicable specifications under normal use, for a period of twelve months from the date of original shipment, unless otherwise specified in the contractual documentation. During the warranty period, ID Quantique will, at its discretion, repair, replace, or issue credit for any defective product. Further, this warranty covers recalibration if the equipment is repaired or if the original calibration has been demonstrated to be erroneous or to have experienced drifts. Please note that:

The warranty can become void if:

- **The equipment has been tampered with, repaired, or worked upon by service personnel not authorized by IDQ.**
- **The warranty sticker has been removed.**
- **The unit has been opened.**
- **The equipment serial number has been altered, erased, or removed.**
- **The equipment has been misused, neglected, or damaged by accident.**

THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES EXPRESSED, IMPLIED OR STATUTORY, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. IN NO EVENT SHALL IDQ BE LIABLE FOR SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES.

1.6 Certification

IDQ certifies that this equipment met its published specifications at the time of shipment from the factory. Applicable standards are listed in the certificate of conformity supplied with the equipment. Contact support@idquantique.com if you have question on the applicable standards.

1.7 Document version

This document is subject to change without notice. Updates to this manual can be found at https://www.idquantique.com/quantum-sensing/products/id1000-time-controller/ or https://www.idquantique.com/quantum-sensing/products/id900-time-controller/.

Date	Product Version	Notes
22 July 2021	1.6.1	Major update to user manual
12 November 2021	1.7.0	**New additions:** Multi-device operation (see Section 7), IP Address assignment (see Section 4.3.3.3)
13 May 2022	1.8.0	User Manual scope expanded to include both the existing ID900 and newly released ID1000 devices. New remote command to turn device LEDs on and off. Simplifications to several SCPI commands for automated device operation.
21 June 2022	1.9.0	ID1000 high-resolution errors reporting (see Section 9.2.2)
21 December 2022	1.10.0	Expanded descriptions and information for timestamp acquisition (see Sections 6.3.4, 6.4.4, 10)
07 July 2023	1.11.0	Expanded descriptions and information for manual IP address assignment (see Section 4.3.3.4), input shaper behaviour and availability (see Sections 8.2.1.1, 8.2.1.2) and on how to configure a deadtime (see Section 8.3.4)

Table 1. Document version

1.8 Legal notice

Trademarks and trade names mentioned in this document remain the property of their respective owners. ID Quantique disclaims any proprietary interest in trademarks and trade names other than its own.

2 Safety and Maintenance

2.1 General Safety Precautions

The following safety precautions must be observed during the operation and servicing of the unit. Failure to comply with these precautions or with specific indications elsewhere in this manual violates safety standards of intended use of the unit. IDQ assumes no liability for the user's failure to comply with these requirements.

Shock Hazard: Before powering on the unit, all grounding terminals, extension cords, and devices connected to it should be connected to a protective ground via a ground socket. Any interruption of the protective grounding is a potential shock hazard and may cause personal injury.

Whenever the ground protection is impaired, the unit is not to be used and must be secured against any accidental or unintended operation. Certain components inside the unit, e.g. capacitors, may be charged even if the unit has been disconnected from its electrical supply.

Whenever the ground protection is impaired, the unit is not to be used and must be secured against any accidental or unintended operation.

Operation of any electrical instrument around flammable gases or fumes constitutes a major safety hazard.

This unit is intended for indoor use only. The air inlet and outlets should be free of any object for at least 5 cm to ensure good cooling.

Do not attempt any internal service or adjustment. Do not replace any components. Any adjustments, maintenance, and repair is to be carried out by an authorized ID Quantique service technician. See Section 1.2 – Getting support for more information.

Note: The warranty is void if the unit has been opened or damaged by improper use. See Section 1.5 – Warranty for further information.

Note: The Time Controller Series must be located in a way that it can be easily unplugged or switched off

Note: ID Quantique shall not be held responsible for any damages to persons or property caused by incorrect installation or use of this appliance.

2.2 Electrical Safety Precautions

2.2.1 Power supply specifications

The Time Controller can operate from any single-phase AC power source, within the requirements given in Section 3.1.2 – Electrical Specification.

2.2.2 Power cable

This unit uses an international safety standard three-wire power cable. This cable serves as a ground when connected to an appropriate AC power receptacle. The type of power cable supplied with each unit is determined according to the country of destination.

The colour coding used in the electric cable depends on the cable. New plugs should meet the local safety requirements and include the following features:

- Adequate load-carrying capacity.
- Ground connection.
- Cable clamp.

Shock Hazard: To avoid electrical shock, do not operate the unit if there are signs of damage to any part of the Time Controller outer surface (covers, panels, etc.).

To avoid serious injury, the following precautions must be observed before powering on the unit:

Do not use an extension cord without a protective conductor. Insert the plug into a power outlet with a protective ground contact.

Before powering on the unit, the protective ground terminal of the unit must be connected to a protective conductor using the unit power cord.

Do not tamper with the protective ground terminal.

2.3 General Maintenance

There are no user-serviceable components in the Time Controller, with the sole exception of the procedures described in this user manual. The Time Controller Series has been designed to require minimal maintenance and to provide reliable operation for many years to come.

To help ensure long, trouble-free operation:


Keep the Time Controller device free of dust.


Do not spill liquids on or into the unit. If the unit does get wet, turn off the power immediately and let the unit dry completely.


Clean the casing with a dry lint-free cloth.

2.4 Calibration verification and tests

The Time Controller Series of detectors do not require any specific maintenance and are designed to offer reliable and accurate operation over their entire lifetime. It is however recommended to check the device calibration on an annual basis to see how it has drifted from its factory-adjusted settings. Factory testing, inspection and calibration are part of the services that ID Quantique can offer to every Time Controller end-user.


If you would like more information on Time Controller calibration verification and testing, please contact ID Quantique at support@idquantique.com for further information.

3 System Overview

3.1 Product Specification

The Time Controller consists of a single physical unit that can be connected to experimental apparatus via five input channels and four output channels, while being controlled by a connected host computer.

3.1.1 Functional Specification

3.1.1.1 Front Panel

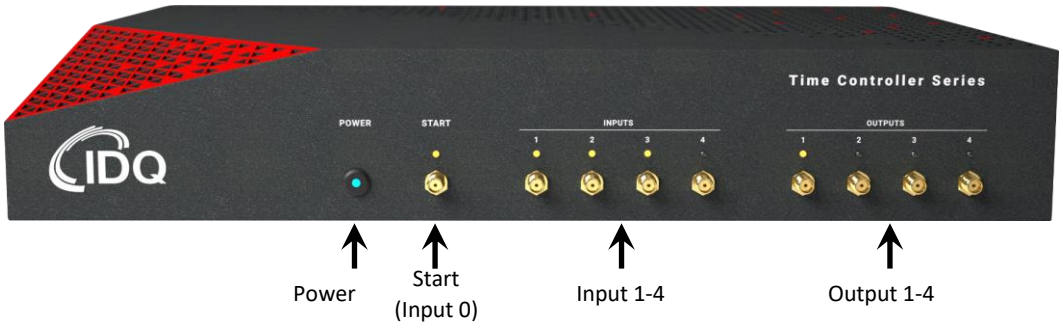


Figure 1: Time Controller front panel

- **Power button:** This button switches the device on, switches the LEDs on and off with short presses, and shuts the device down with presses longer than 2 seconds.
- **Start:** This is a signal input channel that is used when a start reference is required. Use an SMA cable to connect a start signal output from a device to the start input in the Time Controller.
- **Inputs 1-4:** These are the signal input channels. Use an SMA cable to connect a signal output from a device to an input channel on the Time Controller. If you have selected the 'Delay Generator' license for your Time Controller, these input channels may be inaccessible (see Section 3.1.6 – Software).
- **Outputs 1-4:** These are signal output channels. Use an SMA cable to connect a signal output channel to an input channel on the device. Each output can be used to generate a signal for an input channel on the device. If you have selected the 'TCSPC' license for your Time Controller, these output channels may be inaccessible (see Section 3.1.6 – Software).
- **LED Indicators:** Each input or output connector has an LED that indicates the status of the input signal (see Section 5.2 – LED Indicators).

3.1.1.2 Rear Panel

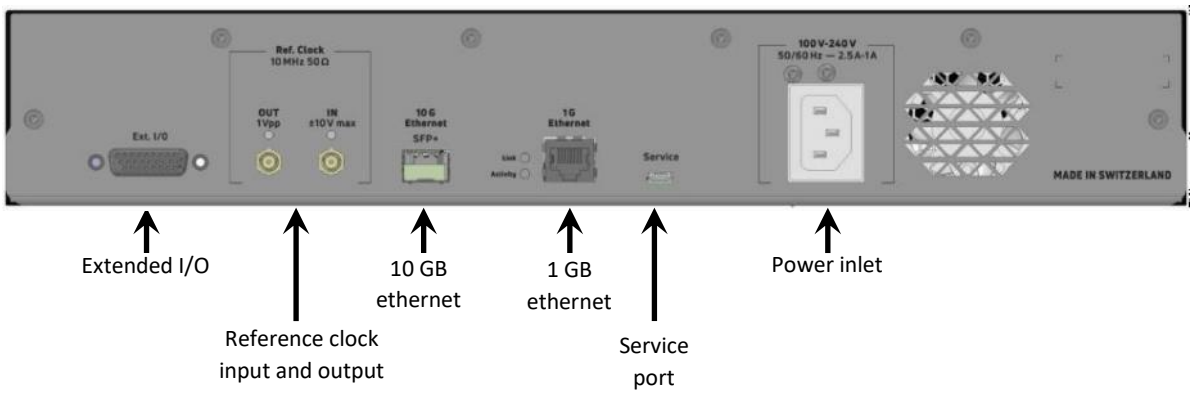


Figure 2: Time Controller rear panel

- **Reference clock:** Use these ports to synchronize the Time Controller with other devices such as Time Controllers, GPS, atomic clocks, scopes, or FPGAs. Use an SMA cable to connect the reference clock of the Time Controller to the reference clock of your other device(s).
- **1 gigabit ethernet:** The Time Controller's main communication port. This port must be connected directly to a computer through an Ethernet cable. The Time Controller should be connected to a computer on a trusted network.
- **Service port:** This port is reserved to IDQ staff for testing and servicing the device. Please do not attempt to use this port.
- **Power inlet:** Use this port to connect the power supply.
- **Extended I/O:** This port is not operational at present.
- **10 gigabit ethernet:** This port is not operational at present.

3.1.2 Electrical Specification

Before operating the Time Controller device, ensure that the power supply meets the requirements given in Table 2. See Section 2.2 – Electrical Safety Precautions for additional information on safety precautions relating to the Time Controller Series power supply.

POWER SUPPLY	
Voltage	100-240 V
Intensity	2.5-1A
Frequency	50-60Hz
Acceptable Mains voltage fluctuation	+/-10%

Table 2: Power Supply requirements for the Time Controller

Warning: Electrostatic Shock Hazard. Ensure all power connections are connected to a ground socket. Failure to connect to ground the device creates a shock hazard which may cause injury to the operator.

3.1.3 Environmental Specification

Ensure that the Time Controller device is kept in an environment meeting the requirements given in Table 3.

WORKING ENVIRONMENT	
Maximum elevation	2000 m
Temperature	5-35°C
Maximum humidity	80% up to 31°C 50% up to 35°C
Overvoltage category	OV II
Pollution degree	PD2

Table 3: Environmental requirements for Time Controller operation

The physical dimensions of the Time Controller device are as follows:

PHYSICAL DIMENSIONS	
Height	63 mm
Width	380 mm
Depth	255 mm
Weight	6.0 kg

Table 4: Physical dimensions of the Time Controller

Warning: Trip Hazard. Ensure all cables attached to the device are laud in a tidy manner, fastened down if necessary. An untidied cable may represent a trip hazard and cause injury to any users walking in the vicinity of the device.

Caution: For optimal operation, ensure that the air inlet and air outlets are free of any obstruction by at least 5 cm.

3.1.4 Host Computer Configuration

The Time Controller must be connected to a host computer to operate. See Table 5 for the recommended minimum hardware, operating system, and software that a computer should have to operate the Time Controller.

HOST COMPUTER MINIMUM SPECIFICATIONS	
Processor	4th gen Intel i7 or 1st gen AMD Ryzen 3
RAM	16 GB
Hard disk speed	100 MB/s
Ethernet	Dedicated 1 Gbps
Operating system	Microsoft Windows 7 Pro

Table 5: Recommended minimum computer specifications

Note: ID Quantique recommends use of the supplied ethernet-to-USB adapter, even if an ethernet port is available on the host computer. Use of the adapter will facilitate a smoother experience in operating the Time Controller software.

3.1.5 Supplied Accessories

In addition to the Time Controller unit, the Time Controller package contains the following accessories:

- **Power cable**, with the appropriate configuration to the region of delivery
- **Ethernet cable**
- **Ethernet to USB adapter**, recommended for ease of operation
- **USB memory stick**, with relevant device drivers, software, licenses, and a PDF copy of this manual

3.1.6 Software

Software allowing the operation of the Time Controller on the designated host computer can be found on the USB memory stick provided in the supplied accessories (see Section 3.1.5 – Supplied Accessories).

Alternatively, the latest version of the Time Controller software can be found on the IDQ website here: https://www.idquantique.com/time-controller-series/.

3.2 Time Controller License

The Time Controller is delivered with a license file pre-installed, selected during the sales process. You can find the exact license you have installed by navigating to the 'Time Controller Application Mode' page with the Time Controller device connected (see Step 4 of Section 4.3.2 – "Time Controller Firmware").

The Time Controller device comes with three license options, with optional extras, as follows:

1. **TCSPC** – Access to time-correlation measurements with the five input channels in 'high speed' mode only (>100 MHz max count rate per channel), with the optional extras:
   - Option a. **HR** – Access to 'high resolution' mode
     ID1000: 1 ps resolution and 4 ps rms jitter for all five input channels
     ID900: 13 ps resolution, 5.7 ps rms jitter for input channels 1 to 4 only
   - Option b. **PG** – Access to the internal FPGA logic, to configure real-time selection filters for up to four-fold coincidences
   - Option c. **4OUT** – Access to the four output channels and the internal delay / pulse generator functionality

2. **Master** – Access to time-correlation measurements with the 5 input channels in 'high speed' mode (>100 MHz per channel), access to the 4 output channels and the internal delay / pulse generator functionality, access to the internal FPGA logic, with the optional extra:
   - Option a. **HR** – Access to 'high resolution' mode
     ID1000: 1 ps resolution and 4 ps rms jitter for all five input channels
     ID900: 13 ps resolution, 5.7 ps rms jitter for input channels 1 to 4 only

⚠ **License Upgrade**: if you would like to upgrade the license of your Time Controller at any time, please contact ID Quantique at support@idquantique.com for further support.

4 Getting Started

4.1 Preparing the Time Controller for Use

Step 1 Familiarize yourself with the handling and safety precautions, and ensure they are followed in the course of setting up, operating, and storing the unit (see Section 2 – "Safety and Maintenance").

Step 2 Remove the Time Controller from its packaging. Ensure you have possession of the Time Controller unit, as well as the necessary supplied accessories (see Section 3.1.5 – "Supplied Accessories").

Step 3 Ensure you have a host computer capable of operating the device (see Section 3.1.4 – "Host Computer ")

Step 4 Ensure that the area of use meets the electrical and environmental requirements (see Sections 3.1.2 – "Electrical Specification" and 3.1.3 – "Environmental Specification").

Step 5 Safely install the Time Controller unit (follow the steps in Section 4.2 – "Hardware Installation").

Step 6 Install the software required for the host computer to operate the Time Controller (follow the steps in Section 4.3.1 – "Host Computer Software").

Step 7 Update the Time Controller firmware (follow the steps in Section 4.3.2 – "Time Controller Firmware").

4.2 Hardware Installation

Carry out the following steps to install the physical Time Controller unit, ready to power on and operate with the host computer.

Warning: Electrostatic Shock Hazard. Ensure all power connections are connected to a ground socket. Failure to connect to ground the device creates a shock hazard which may cause injury to the operator.

Warning: Trip Hazard. Ensure all cables attached to the device are laud in a tidy manner, fastened down if necessary. An untidied cable may represent a trip hazard and cause injury to any users walking in the vicinity of the device.

Step 1 Place the Time Controller unit on a stable flat surface, in an environment meeting the conditions specified in Section 3.1.3 – "Environmental Specification".

Caution: For optimal operation, ensure that the air inlet and air outlets are free of any obstruction by at least 5 cm.

Step 2 Insert the supplied power cable into the power inlet on the rear panel of the device.

Step 3 Insert the other end of the supplied power cable into a grounded wall socket or grounded uninterruptible power supply (UPS).

Step 4 Insert the ethernet cable into the 1GB Ethernet port on the rear panel of the device.

Step 5 Connect the other end of the ethernet cable to the host computer.

Note: ID Quantique recommends use of the supplied ethernet-to-USB adapter, even if an ethernet port is available on the host computer. Use of the adapter will facilitate a smoother experience in operating the Time Controller software.

Step 6 Lightly screw each SMA connector onto the relevant Input, Output or Start channel on the front panel of the device.

Caution: Do not forcibly attach an SMA connector onto an SMA port. This may permanently damage the SMA cable in question.

The device can now be powered on safely (see Section 5.1 – "Powering the Time Controller on and off").

4.3 Software Installation

4.3.1 Host Computer Software

The software package for operating the Time Controller via a host computer can be found on the USB memory stick supplied in the delivery of the Time Controller device, or the latest version can be found on the IDQ website (see Section 3.1.6 – Software).

Step 1 Insert the USB memory stick into the host computer or download and unzip the online software package.

Step 2 In Windows Explorer, navigate to the directory '[*software package location*] > TimeController_Vx_y_z'.

Step 3 Double click the 'TimeController_SW_x_y_z.exe' Windows installer package to launch the installer and install the Time Controller software.

Step 4 Open the newly installed Time Controller software. If the software opens without error, the host computer software is now successfully installed, and the remaining steps can be skipped. If an error does arise, complete the remaining steps 5 and 6.

Step 5 In Windows Explorer, navigate to the directory '[*software package location*] > TimeController_Vx_y_z > Redistributables'.

Step 6 Install 'dotNetFx45_Full_setup.exe'.

4.3.2 Time Controller Firmware

Upon release of software updates, the firmware embedded in the Time Controller may need to be updated. To update the device firmware, carry out the following steps:

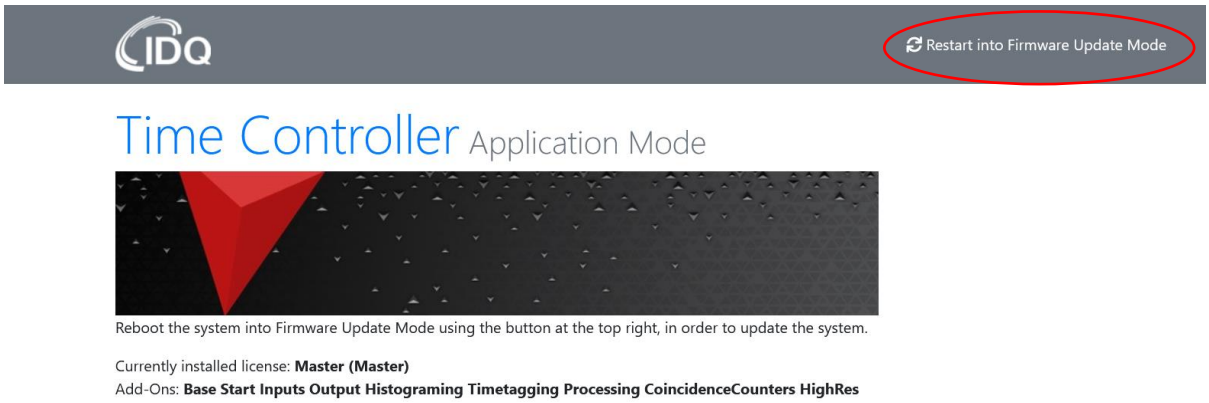
Step 1 Carry out the device installation steps in Section 4.1, connecting the device to the host computer.

Step 2 (*If not using the downloaded software package*) Connect the supplied USB memory stick to the host computer.

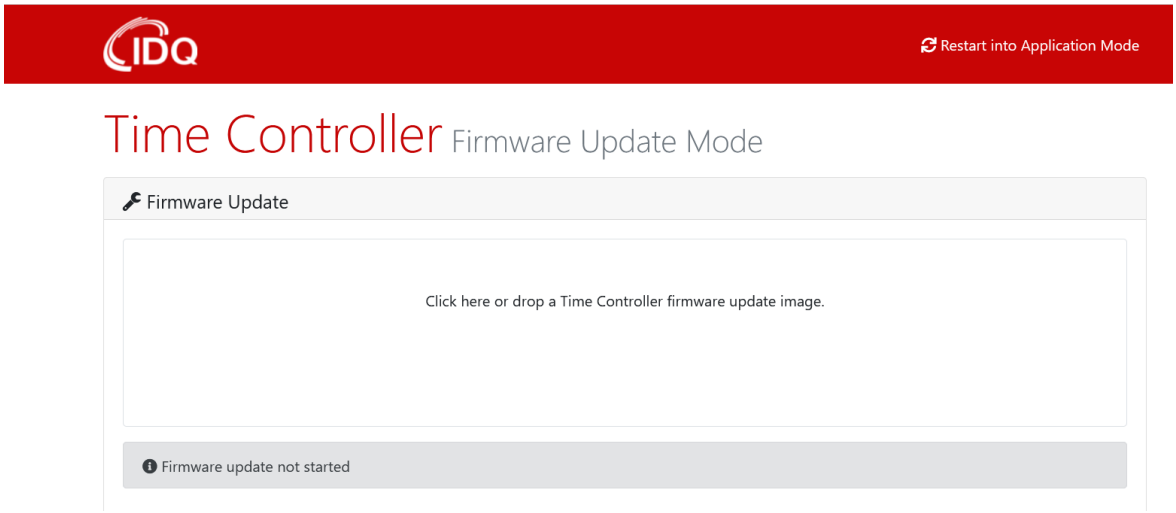
Step 3 With the Time Controller correctly installed as in Section 4.2 – "Hardware Installation", press the 'Power' button on the device's front panel to power the device on.

Step 4 In a web browser, navigate to http://169.245.XXX.1YY:8080, where 169.245.XXX.1YY is the IP address of your Time Controller device (see Section 4.3.3 – "Finding your Time Controller IP Address"). The "Time Controller Application Mode" page will open.

Step 5 Click the button "Restart into Firmware Update Mode" in the top right-hand corner. A message is displayed indicating that the system is restarting. The Time Controller Firmware Update Mode page is displayed when the system is ready.



Step 6 Click in the "Software Update" box. Note, for versions earlier than 1.4, the Time Controller Firmware Update Mode page header will be blue. For versions of 1.4 or later, the Time Controller Firmware Update Mode page header will be red.



Step 7 In the "Open" file dialogue, navigate to the directory '[*software package location*] > TimeController_V*x_y_z*'.

Step 8 Select and accept the file 'TimeController_Application_ESW_*x_y_z*.swu' for update, where '*x_y_z*' is the version of the firmware being installed.

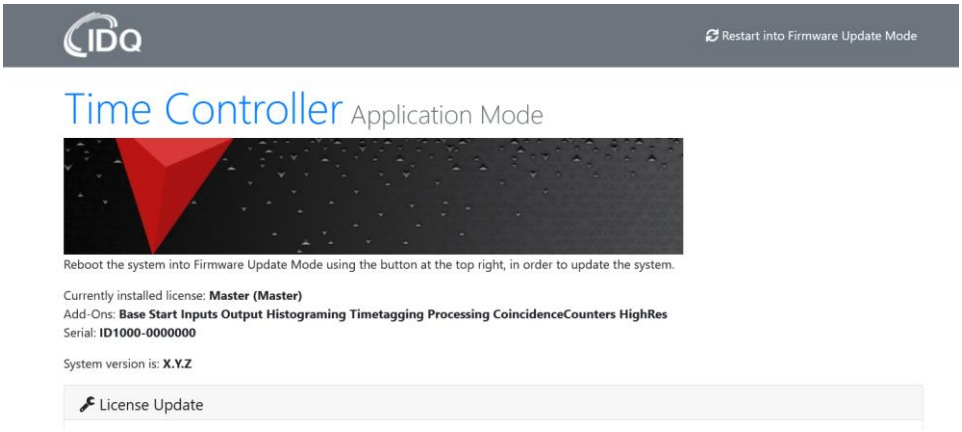
Caution: Do not power off the Time Controller while the firmware update is in progress.

Step 9 Wait for the progress bar to reach 100% and the system to reboot. Note that the progress bar will remain at 0% for one to two minutes. If the update fails, go to Step 12.

Step 10 Once the update is complete, a pop-up with the text "The system will restart. Please be patient, as restarting takes about one minute" will appear.

If the pop-up message is visible for more than two minutes, or if the device does not restart, then conduct a forced restart of the device by holding the power button down for at least 5 seconds, and then power the device on again. Then, wait approximately one minute and refresh the Time Controller Application Mode / Time Controller Firmware Update Mode page.

Step 11 In the refreshed Time Controller Application Mode page and check the text reading "System version is: ..."



Success: if the update was successful, then the system version '*x_y_z*' from Step 8 will now be visible as "System version is: x.y.z" in 0, and the remaining steps can be ignored.

Failure: if the update was not successful, and if you are operating an ID900 Time Controller device, proceed to Step 12.

Following an unsuccessful firmware update, and if you are operating an ID900 Time Controller device:

Step 12 With the device still powered on and connected to the host computer, repeat Step 4 to Step 7 of this section.

Step 13 Select and accept the file 'ID900_Recovery_ESW_1_4_0.swu' for update.

Caution: Do not power off the Time Controller while the firmware update is in progress.

Step 14 Repeat Step 9 and Step 10, waiting for the firmware update to complete with the recovery image.

Step 15 With the recovery firmware image installed, and the device still powered on and connected to the host computer, repeat Step 4 to 0 to attempt installation of the firmware image 'TimeController_Application_ESW_*x_y_z*.swu'

Support: if the firmware update is still failing after following these steps, please contact ID Quantique at support@idquantique.com for further support.

4.3.3 Finding your Time Controller IP Address

The Time Controller uses a fixed IP address, unique to each device, in connecting with the host computer. In addition to this fixed IP address, the Time Controller is also assigned a dynamic IP address when the Time Controller starts and is connected to the host computer or network (see Section 4.3.3.3 – Automated IP Address Assignment).

You may be able to find the IP address from the GUI of the Time Controller Software when your Time Controller device is connected. Otherwise, you can find the device's IP address printed on your device.

4.3.3.1 Via Time Controller Software

To find your Time Controller device's IP address through the Time Controller software, ensure the device is powered on and connected to the host computer, and open the Time Controller application on the host computer. Click on the 'About' menu in the toolbar. The IP address of a fully connected device will be shown in the resulting pop-up window (see Figure 3).

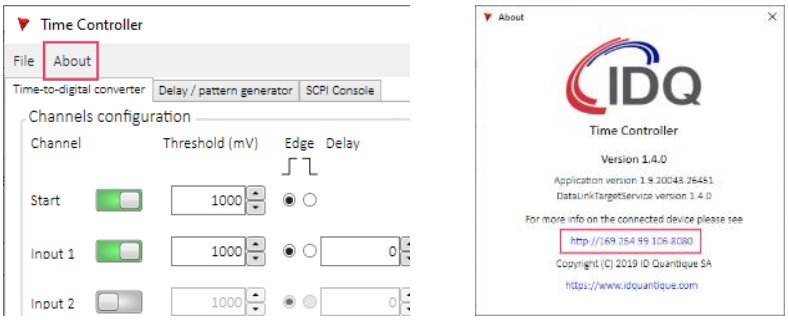


Figure 3: How to find your Time Controller device's IP address if it is fully connected to the host computer.

4.3.3.2 Via Printed Sticker

If you are not able to find the device's IP address through the Time Controller software, search for a sticker on the rear panel of your Time Controller (see Figure 4). This sticker is printed with the device's serial number, and either with or without the device's IP address.

Figure 4: Sticker on the rear panel of the Time Controller device, printed with the serial number only (ID900, left image) or with both the serial number and IP address (ID1000, right image)

If the IP address is printed on this sticker, write this down and proceed with using your Time Controller.

If no IP address is printed, you can ascertain the IP address from the serial number. The serial number follows a format of SN: "**AAAA**0**BB**T010", while the IP address follows the format of IP: "169.245.**XXX**.1**YY**". To translate the serial number to an IP address:

- "BB" in the serial number the same as "YY" in the IP address
- "AAAA" in the serial number is related to "XXX" in the IP address in the following way:

AAAA	XXX
1734	99
18**	100
1908	101

For example, a Time Controller device with the serial number "17340006T010" would have and IP address of "169.254.99.106".

Support: if you are unable to find your Time Controller device's IP address after following the instructions in this section, please contact ID Quantique at support@idquantique.com for further support.

4.3.3.3 *Automated IP Address Assignment*

New in release 1.7.0 of the Time Controller software, to support use of the Time Controller device over a local area network, a dynamic IP address is additionally assigned to the Time Controller when it starts.

To make use of the dynamic IP address, when selecting the device in the Time Controller application (see Section 6.2.1 – Configuring Time Controller Settings), select the relevant device from the drop-down "Device" menu, and the corresponding device IP will appear alongside.

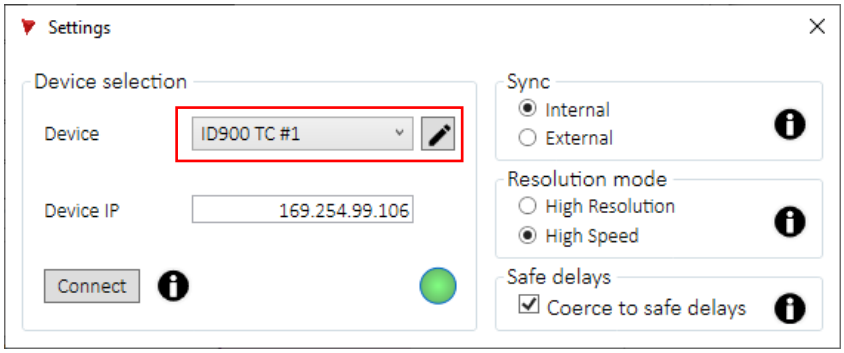


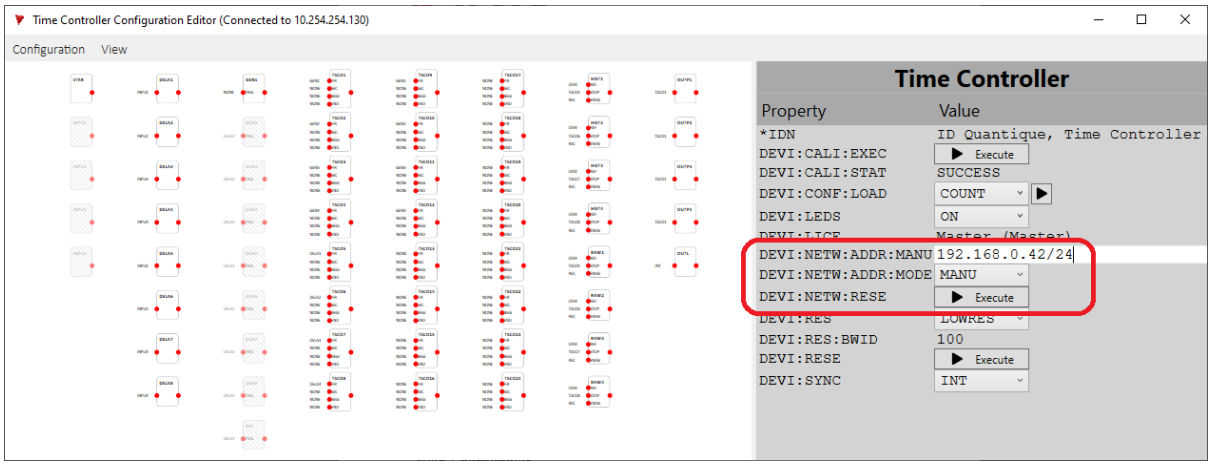
Figure 5: Device selection in the Time Controller application

4.3.3.4 *Manual IP Address Assignment*

New in release 1.10.0 of the Time Controller software, to support the manual assignment of a static IP address through its SCPI command interface (see section 9.2.1).

To easily set it, open the Time Controller Configuration Editor, connect to its factory assigned IP address (see section 4.3.3.2) or automatically assigned IP address (see section 4.3.3.3) and then:

1. set DEVI:NETW:ADDR:MANU property with the desired IP address
2. set DEVI:NETW:ADDR:MODE property with the "MANU" value
3. reset the Time Controller network interface by either:
    a. clicking the Execute next to DEVI:NETW:RESE (takes a few seconds)
    b. restarting the Time Controller (takes about a minute or two)



Finally, ensure the Time Controller is connected to a network interface compatible network with the IP address you've configured. You should now be able to connect to your Time Controller with its new IP address.

5 Operating the Time Controller Hardware

5.1 Powering the Time Controller on and off

Powering the Time Controller on and off is mediated by the 'Power' button on the device's front panel (see 3.1.1.1 – "Front Panel").

Power on: With the Time Controller correctly installed as in Section 4.2 – "Hardware Installation", and with the device powered off, press the 'Power' button on the front panel to power the device on.

Power off (normal): With the device powered on, hold the 'Power' button on the front panel for 2 to 5 seconds to power the device off. Upon successful shutting down, the cooling fan will cease operation.

Power off (forced shutdown): If the device is powered on but unresponsive, hold the 'Power' button on the front panel for more than 5 seconds to force the device to shut down.

Note: Holding the 'Power' button for less than 2 seconds will not cause the Time Controller to shut down.

Caution: Pressing the power button less for than 2 seconds will not shut down the device: the device's LEDs will be shut off, but the Time Controller will continue to be turned on and fully operational (see Section 5.2 – "LED Indicators")

5.2 LED Indicators

Each input or output connector has an LED that indicates the status of the input signal:

LED indicator	Description
Off	Channel disabled OR Channel enabled with LED indicator turned off.
Blinking blue (all)	System is starting up OR System has been placed in recovery mode.
Solid white (single channel)	The input channel has been internally linked to one of the output channels, e.g. for recalibration.
Solid amber (single channel)	Channel enabled, and signal detected with no error.
Blinking amber (single channel)	Channel enabled, but no signal detected.
Single red flash (single channel)	(*Only in HiRes mode*) A single sampling error has occurred (see Section 5.2.1 – Input sampling errors). Please follow the instructions in the GUI.
Solid/flickering red (single channel)	(*Only in HiRes mode*) Multiple/continuous sampling errors are occurring (see Section 5.2.1 – Input sampling errors). Please follow the instructions in the GUI.
Blinking red (all)	The distribution of clock signals within the Time Controller has lost synchronicity. If operating an ID900 Time Controller, please manually restart the Time Controller system. If using an external clock signal, and a manual system restart does not fix the error, try increasing the signal's pulse amplitude to TTL levels and/or adjusting the frequency closer to 10 MHz.

Table 6: LED indicator status descriptions

In an environment where room light must be kept to an absolute minimum, it may be useful to switch off the LED indicators on the Time Controller's front and rear panel. This can be controlled using either:

- the SCPI command interface (see 9.2.1 – "Device (DEVIce)")
- the 'Power' button on the device's front panel (see 3.1.1.1 – "Front Panel").

Turn off LEDs: To turn off the lit LED indicators on the Time Controller's front and rear panels, press the 'Power' button once.

Turn on LEDs: With the Time Controller device powered on and the LED indicators un-lit, to turn the LED indicators on press the 'Power' button once.

⚠ **Note:** Holding the 'Power' button for 2 seconds or more will cause the Time Controller to shut down.

5.2.1 Input sampling errors

Input sampling errors, indicated by a single flash on the input channel's LED indicator (see Table 6 above) may occur for the following reasons, although only ever in High Resolution mode:

- If using an ID900 Time Controller Series device, when the average event rate on the channel exceeds 25MHz
- If using the ID900 Time Controller Series device, when the time between two events is shorter than 5 ns
- The slew rate of the signal around the threshold level is not sufficiently clean (noise-free) and/or steep (50 V/µs)

⚠ **Note:** If the LED is still red, even though all points above are OK, the user can perform a recalibration by clicking the "Recalibrate" button at the bottom right of the Time Controller GUI, or by sending the command DEVIce:CALIbration:EXECute and wait while the command DEVIce:CALIbration:STATus? returns RUNNING until it returns SUCCESS or FAILURE. If this still does not solve the problem, try turning off and on the device.

5.3 I/O specifications

There are two modes in which the Time Controller can acquire data:

- **High speed:** Greater maximum count rates at the expense of timing resolution. All input and output channels are enabled, including the Start channel.
- **High resolution:** Greater timing resolution, at the expense of maximum count rates. All input and output channels are enabled for the ID1000, while the Start channel is disabled for the ID900.

Depending on the acquisition mode and Time Controller Series model, the specifications for the input and output channels are as follows:

ID1000 Time Controller Series	**Start & Inputs 1 to 4**		**Outputs 1 to 4**
	High speed	High res.	
Voltage range (50Ω)	-3 V to +3 V	-3 V to +3 V	-3 V to +3 V
*Max. input rate**	5 x 100 MHz	300 MHz (across all channels)	125 MHz
Max. timestamp rate	10 M events/s (across all channels)		-
Min. time-bin width (digital resolution)	100 ps	1 ps	-
RMS jitter (timing precision)	28 ps	4 ps	28 ps

** Including single-channel counters, coincidence counters, and histogram processing*

Table 7: Specifications for ID1000's input and output channels

ID900 Time Controller Series	**Start**	**Inputs 1 to 4**		**Outputs 1 to 4**
	High speed only	High speed	High res.	
Voltage range (50Ω)	-3 V to +3 V	-3 V to +3 V	-3 V to +3 V	-3 V to +3 V
*Max. input rate**	1 x 100 MHz	4 x 100 MHz	4 x 25 MHz	125 MHz
Max. timestamp rate	10 M events/s (across all channels)			-
Min. time-bin width (digital resolution)	100 ps	100 ps	13 ps	-
RMS jitter (timing precision)	28 ps	28 ps	5.7 ps	28 ps

**Including single-channel counters, coincidence counters, and histogram processing*

Table 8: Specifications for ID900's input and output channels

Depending on the license you have selected for your Time Controller, the input channels or the output channels may be inaccessible, and/or 'high resolution' mode may be unavailable (see Section 3.1.6 – Software).

5.3.1 Start channel and Input channels 1 – 4

Use an SMA cable to connect an input signal to the Time Controller on input channels 1—4 or the Start channel.

Caution: the input signal level must be between –3V and +3V (50Ω) to avoid causing irreversible damages to the device. The discriminator level can be set between –2 V and +2 V in steps of 1 mV

The shortest input pulse that can be registered by the Time Controller is 100 ps.

The Start channel is only available when the Time Controller software is set to high-speed mode. In high-resolution mode, one of input channels 1-4 must be used as the start reference.

5.3.2 Output channels 1 – 4

The output channels can be used to output a signal from the Time Controller to another device or back into an input channel on the Time Controller. This signal can be generated by the Time Controller or, it can be an input signal that has been processed by the time controller and then output to a device.

The output channel can generate a NIM signal or a TTL signal. For very fast signals, NIM is preferable. TTL must be used without a 50 Ω termination on the connected equipment.

If a TTL output signal is used without termination, or with high-Z termination, the output pulse length should be a minimum of 50 ns per meter of cable between the devices, to prevent attenuation of the electrical pulse to unacceptable levels.

A summary of output signal levels is given in below in Table 9.

Output	Termination	Logic “0”	Logic “1”	Min. pulse width
NIM	50 Ω	0 V	–0.8 V	1 ns
TTL	High-Z	0 V	+5.0 V	10 L/u (*)

* u is the speed of the electrical signal in the cable (approximately 2×10^8 ms^{-1}, about 2/3 the speed of light in a vacuum), and L is the length of the cable. For a 1 m cable, the minimum pulse length is 50 ns.

Table 9: Output channel voltage levels

5.3.3 Reference Clock

Use the reference clock inputs and outputs to synchronize the Time Controller with other devices. For example, additional Time Controllers, GPS, atomic clocks, scopes, or FPGAs.

- Connect an external device to the Reference Clock IN port to supersede the internal master clock of the Time Controller with the master clock of the external device.
- Connect the Reference Clock OUT port to an external device to supersede the master clock of external device with the master clock of the Time Controller.
- Connect the IN and OUT ports to connect several devices in a daisy chain.

Use an SMA cable to connect the reference clock of the Time Controller to the reference clock of your other device(s).

This port expects a repetitive signal (Sine wave or square wave) with a frequency of 10±0.025 MHz and a maximum 10 V peak-to-peak voltage (e.g. maximum -5 V to 5 V over 50 Ω). Smaller voltages also work well. The device-to-device jitter obtained with this connection is less than 2 ps.

6 Operating the Time Controller Software

With the Time Controller hardware correctly installed (see Section 4.2– “Hardware Installation”) and Time Controller software installed (see Section 4.3 – “Software Installation”), you are now ready to use your Time Controller to take time-resolved measurements.

The ability to collect data from the input channels, use of the output channels, and the availability of ‘high resolution’ mode will depend on the license you have selected for your Time Controller (see Section 3.1.6 – “Software”).

6.1 Navigating the Time Controller Software

To begin using the Time Controller device, after ensuring the Time Controller device is powered on and connected to the host computer, open the ‘Time Controller’ application installed in Section 4.3.1 – “Host Computer Software” on your host computer.

6.1.1 Main Window

Upon opening, the main window will appear, with a smaller Settings window used to configure the connection between the host computer and the Time Controller device. The features of the Time Controller software are organized into menus and workspaces. These are accessible at the top of the main window.

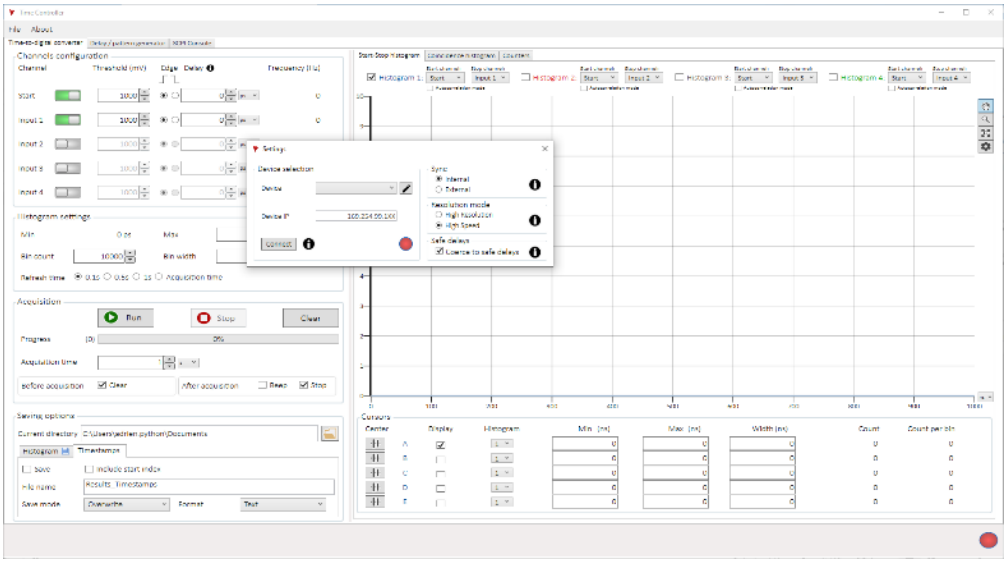


Figure 6: Time Controller software main window

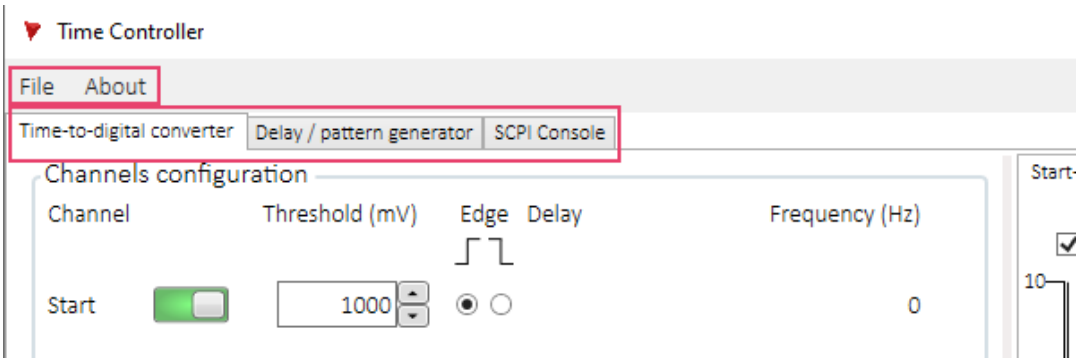


Figure 7: Time Controller software menus and workspace tabs

6.1.1.1 Menus

- **File menu:** Use the 'File' menu to configure the device settings (see Section 6.2.1) or open a new window for use of an additional connected Time Controller device.
- **About menu:** Use the 'About' menu to view the version of the installed Time Controller software, as well as the IP address and version of the device's installed firmware.

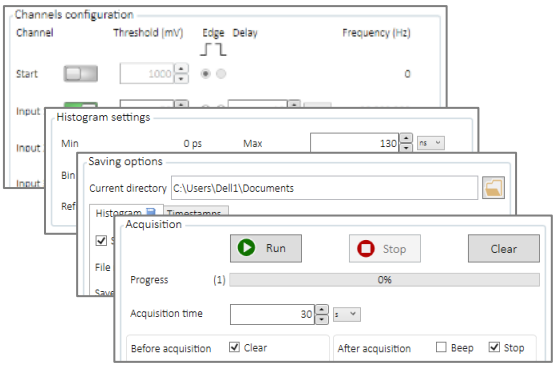
6.1.1.2 *Workspaces*

- **Time-to-digital converter:** Use the 'Time-to-digital converter' workspace to configure the input channels, and to read and record data from histogram and time-tagging measurements.
- **Delay / pattern generator:** Use the 'Delay / pattern generator' to configure the output signal for the output channels.
- **SCPI Console:** Use the 'SCPI Console' to input SCPI commands to interact with the Time Controller device, and to view the SCPI commands being pushed to the Time Controller device by the Time Controller GUI.

6.1.2 *Time-to-digital converter*

The Time-to-digital converter workspace is used to configure the parameters of the input detector channels, control the acquisition and saving of histogram and time-tagging data, and display measured histograms and detector channel count rates.

This left-hand side of this workspace contains four areas of interest:



1. **Channels configuration:** Control the active status, threshold voltage, pulse detection mode, and hardware delay for each of the Start and input channels (see Section 6.2.2)
2. **Histogram settings:** vary the number and width of your histogram time bins (see Section 6.3.2)
3. **Acquisition:** Control the data acquisition settings (see Section 6.3.5)
4. **Saving options:** Select the details for saving your histogram and time-tagging data (see Section 6.3.3)

The right-hand side of this workspace contains three tabs of interest, in which different kinds of measurements can be viewed:

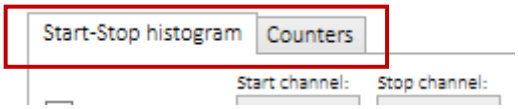


Figure 8: Measurement viewing tabs

1. **Start-Stop histogram:** View the histograms for up to four pairs of input (or Start) channels (see Section 6.1.2.1).
2. **Counters:** View the single-detector count rates, or the double, triple, or quadruple detection coincidence rates (see Section 6.1.2.2).

6.1.2.1 Start-Stop histogram

The data displayed in the Start-Stop histogram presents the number of coincident detection events between two inputs (or Start) channels as a function of their relative delay, for up to four pairs of channels. When a detection is registered in the designated 'Start channel' at time t, and a detection is registered in the 'Stop channel' at time $t + \tau$, the number of counts in time bin τ increases by one.

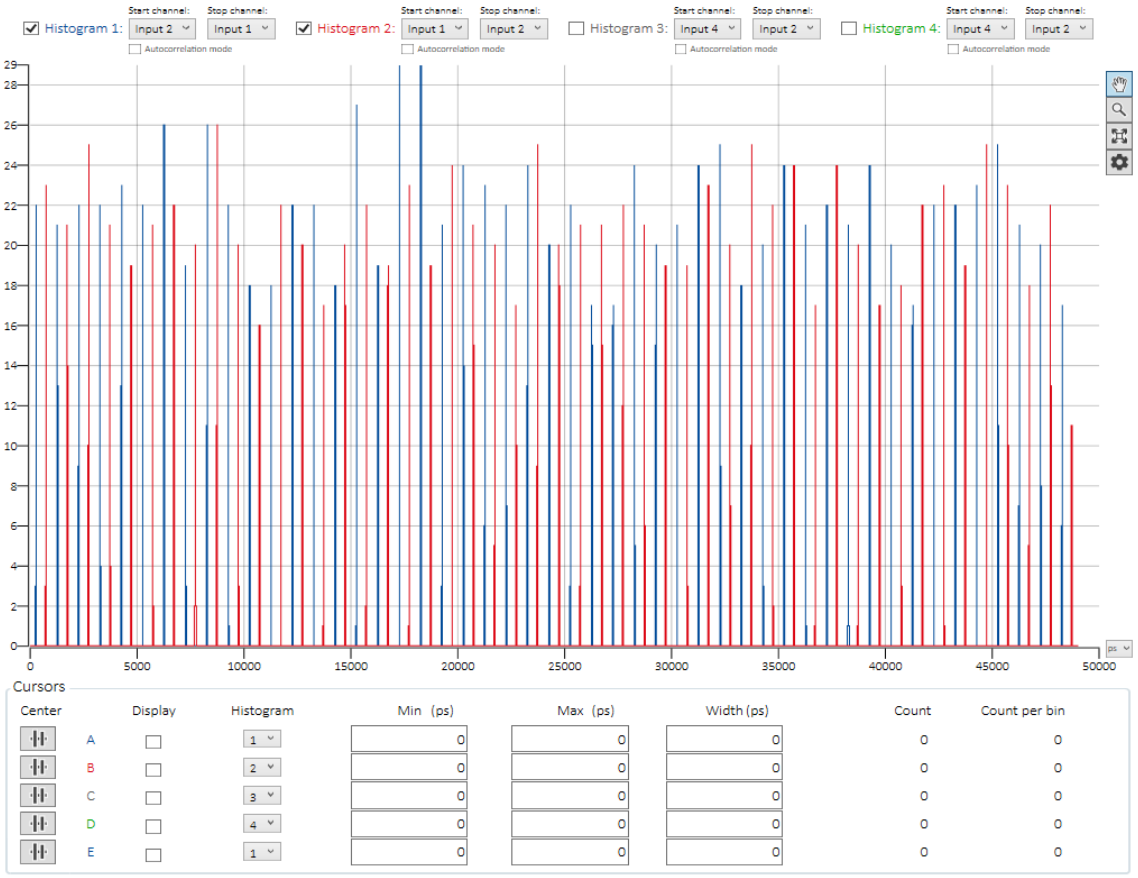


Figure 9: Start-Stop histogram view (near-identical to the Coincidence histogram view)

To choose which histograms you wish to display, select, or deselect the relevant checkboxes at the top of the view, to the left of 'Histogram 1' to 'Histogram 4'.

To select the start and stop channels for each histogram, click on the drop-down menus immediately to the right of each histogram name. Note that in high resolution mode you will only be able to select input channels 1—4, it will not be possible to select the 'Start' input channel.

You can control the histogram graph figure in the following ways:

- Translate the histogram view by clicking and dragging with the hand tool.
- Zoom in to an area of interest with the magnifying glass tool.
- Reset the zoom level with the zoom-out tool.
- Make the legend visible or invisible, control the auto-scaling of each axis, and select linear or log 10 scaling for each graph axis with the settings tool.

Additionally, you can inspect up to five windows of interest in the displayed histograms with the Cursors tool.

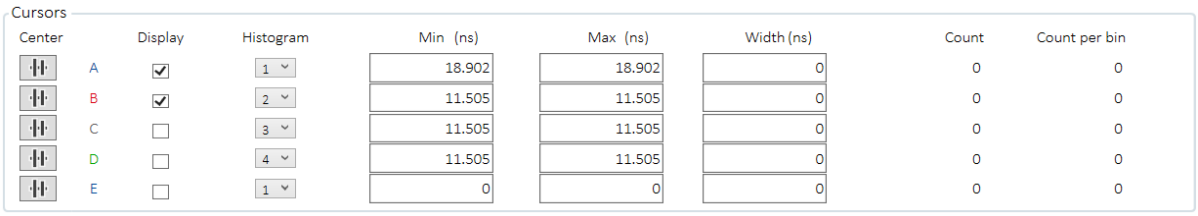


Figure 10: Histogram cursor control

Select or deselect the checkbox next to each cursor in the dialogue to choose which will be visible. Select the histogram that will be inspected in the drop-down 'Histogram' menu of the corresponding cursor.

To select the window of interest, type in the Min time bin value, as well as the Max or Width value. Alternatively, select the Max and Min values on the graph itself by dragging the cursor with the hand tool.

In this way, you can inspect the total number of counts in this window, as well as the average number of counts per time bin.

6.1.2.2 Counters

The third tab in the Time-to-digital converter workspace allows you to view the single detector-channel count rates, or the double-, triple- or quadruple-coincidence count rates.

To view the count rates for a single channel, at the top of the Counters view select the checkbox next to 'Start', '1', '2', '3' or '4' as appropriate, and specify the duration for each measurement in the 'Integration window' field.

To view coincident count rates, the channels of interest are separated by a forward slash. For example, select '1/2' for double-detector coincidences between channel 1 and 2, or '1/3/4' for

triple-detector coincidences between channels 1, 3 and 4, or '1/2/3/4' for quadruple coincidences on input channels 1, 2, 3 and 4.

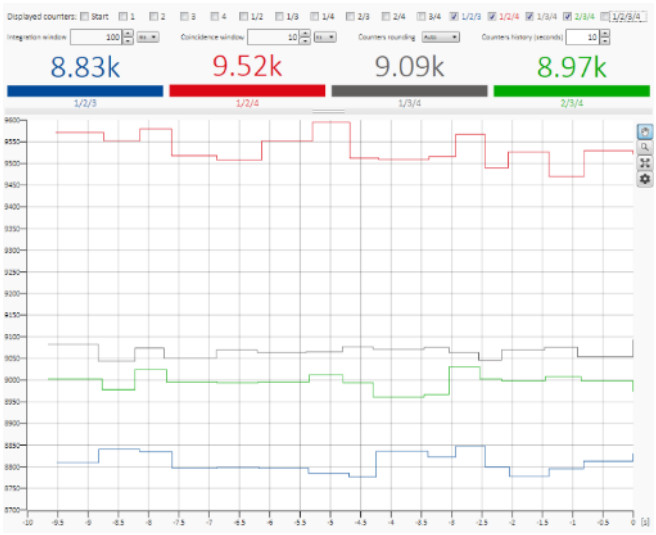


Figure 11: Counters view

When viewing coincident count rates, specify the time window in which detection events are considered simultaneous in the 'Coincidence window' field.

6.1.3 Delay / pattern generator

The Delay / pattern generator workspace allows you to control the four output channels and four of the internal signal generators.

See Section 6.2.3 – "Configuring Output Channels" for instructions on how to configure the pattern generators.

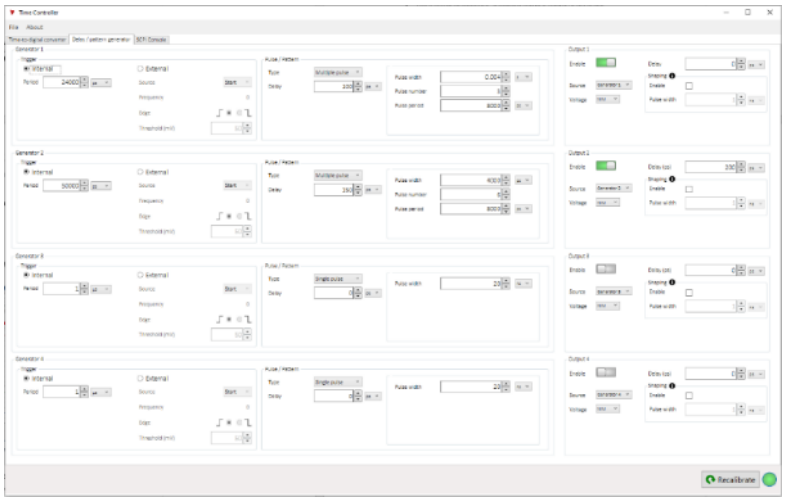


Figure 12: Delay / pattern generator workspace

6.1.4 SCPI Console

The SCPI Console workspace can be used to manually issue SCPI commands to the Time Controller device, load previously saved device configurations, and view the SCPI commands that the Time Controller GUI has been pushing to the device.

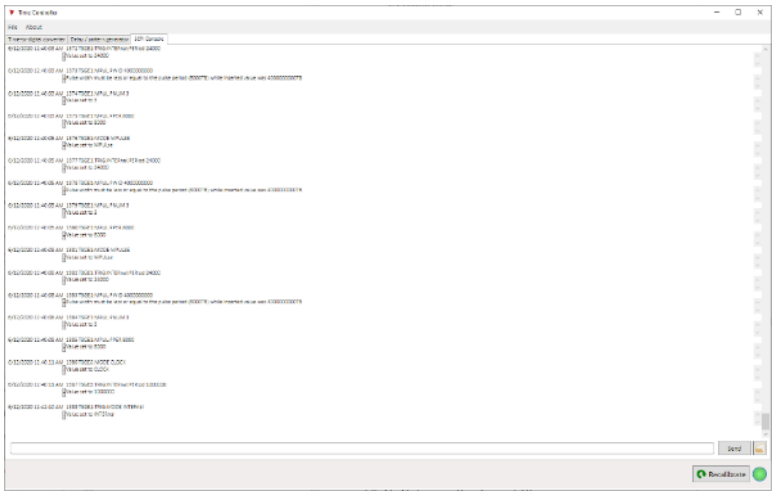


Figure 13: SCPI Console workspace

To issue SCPI commands to the Time Controller device, type the command in the input field at the bottom of the workspace and click **Send**.

To load a previously saved device configuration, click the folder icon on the right-hand side, and select the desired configuration file. Device configuration files are generated by navigating to 'File > Save Settings', saving the current device settings as a '.bin' file with the name and location of your choice.

Commands issued through the SCPI Console, or any other means outside of the Time Controller GUI, will not be reflected in the Time Controller GUI. The Time Controller software only registers a change in device parameter when the command is issued via the Time Controller GUI.

6.2 Settings and Configuration

6.2.1 Configuring Time Controller Settings

Use the Settings window to connect to your Time Controller device, or to change the Sync or Resolution modes. To open this window, click File > Settings. This is the default view when you open the Time Controller software.

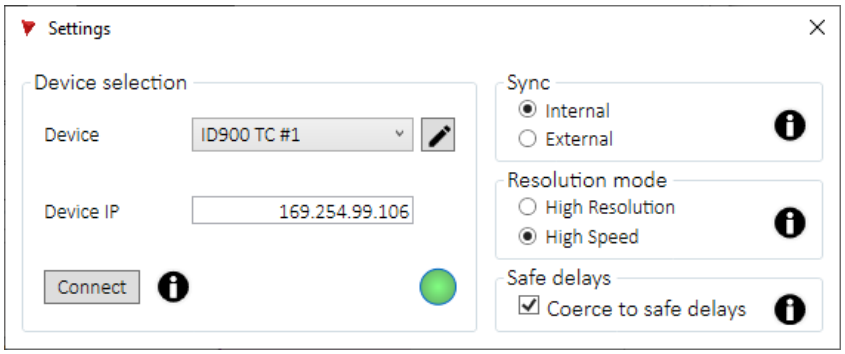


Figure 14: Time Controller Settings window

6.2.1.1 Device selection

Use this to connect to a time controller device:

- **Device:** This shows the name of the connected device. You may be able to select the name of one or more Time Controllers in this drop-down menu if used before, subsequently auto-populating the "Device IP" field. The pencil button next to the selection field allows you to rename the device.
- **Device IP:** This shows the IP address for the selected device. Enter the IP Address for the relevant Time Controller here if you have not done so already.
- **Connect:** Press this button to connect to the selected device (this may take 10-20 seconds). The colour indicator will display the connection status:
    - Red indicates that the device is not connected.
    - Green indicates that the device is connected.

6.2.1.2 Sync

Use this to configure the reference clock to be used by the connected Time Controller device.

- **Internal:** Use the internal clock of the Time Controller device.
- **External:** Use an external time clock that is connected to the Time Controller device.

6.2.1.3 Resolution mode

Depending on the license in use, there are two modes of operation for the Time Controller device (see Section 5.3 – "I/O specifications" for additional detail):

- **High Resolution:** Greater timing resolution, at the expense of maximum count rates. All input and output channels are enabled, except for the Start channel.
- **High Speed**. Greater maximum count rates at the expense of timing resolution. All input and output channels are enabled, including the Start channel.

6.2.1.4 Safe delays

In configuring the input and output channels (see Sections 6.2.2 and 6.2.3), the user can specify a signal delay up to 1 second, at a precision of 1 picosecond. However, as the signal events are stored in a buffer before being released after the desired delay, the buffer might overflow if the input signal frequency is too high.

By selecting the 'Coerce to safe delays' checkbox, the Time Controller software limits the input and output delays to a secure maximum of 4 microseconds each, to prevent such an overflow. If this

option is disabled, a delay field's text will be coloured when its value is above 4 microseconds. Hovering the mouse over the coloured text will display a warning message stating the maximum event frequency that can be reliably registered with for a given input or output delay (see Figure 15).

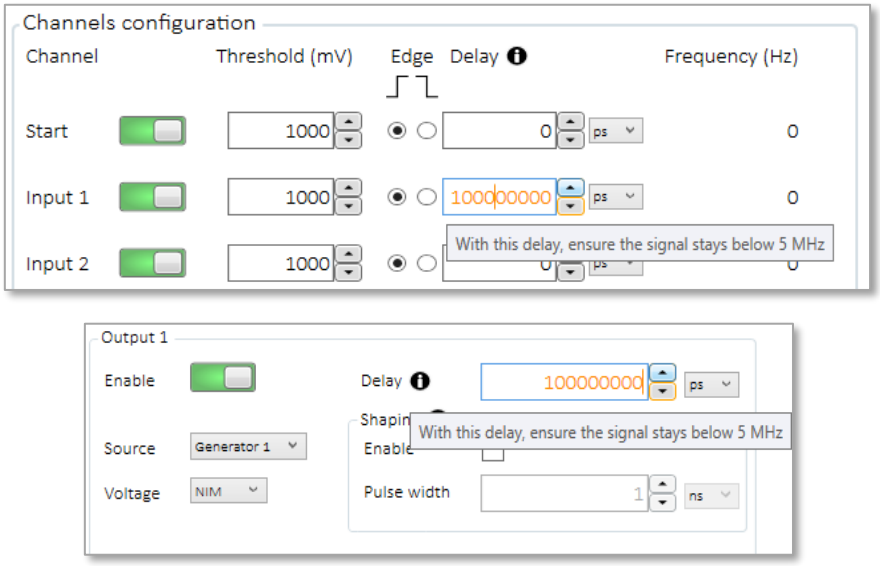


Figure 15: Warning message for an unsafe input delay (top) or output delay (bottom), if 'Coerce to safe delays' is deselected in the device settings

6.2.2 *Configuring Start and Input Channels*

Use the Channels configuration view to configure the start and input channels:

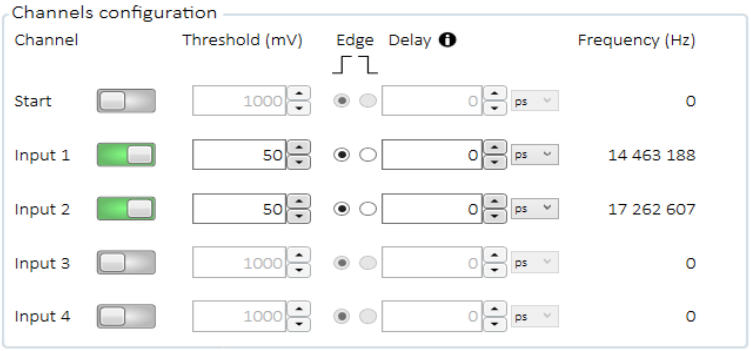


Figure 16: Input channels configuration view

- **Channel:** Flip the toggle switch next to each channel name to make that channel active (green) or inactive (grey).
- **Threshold (mV):** Set the voltage (in millivolts) that corresponds to a detection event on the incoming pulse. Any incoming pulses that fail to reach this threshold level will be disregarded.
- **Edge:** Select whether a detector count is registered on the rising or falling edge of an incoming pulse. A count is registered at the time the incoming pulse reaches the threshold voltage on the pulse's rising or falling edge (as selected).

- **Delay:** Specify a relative signal delay on each channel as required (up to 1 s with 1 ps precision).
- **Frequency (Hz):** View the single-channel count rate with the specified Threshold and Edge choices.

6.2.3 Configuring Output Channels

In the Delay / pattern generator workspace of the Time Controller software, there are four pulse / pattern generators that can each be configured and mapped to one or more output channels.

To produce a user-created signal for one of the generators, select 'Internal' trigger, and select the duration of a single period of the pattern in the 'Period' field.

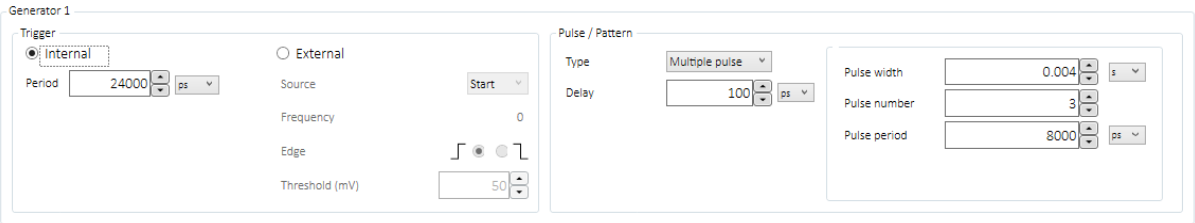


Figure 17: Delay / pattern generator configuration view

To generate a signal triggered by one of the input channels, select 'External' trigger, and specify the input channel Source, Edge, and Threshold choices, similar to Section 6.2.2. Given these choices, you will see the rate of pulses being generated in the 'Frequency' field.

There are three choices for the type of pulse pattern:

1. **Clock:** (Internal trigger only) The generator produces a binary pulse train with a 50% duty cycle and periodicity specified in the trigger's 'Period' field.
2. **Single Pulse:** At the start of each internal triggered period, or on registering an external trigger event, the generator outputs a single pulse of a duration specified in the 'Pulse width' field.
3. **Multiple pulse:** At the start of each internal triggered period, or on registering an external trigger event, the generator outputs a train of up to seven pulses, each pulse with an identical duration specified in the 'Pulse width' field, and where the number of pulses and overall duration of the pulse train are specified in the 'Pulse number' and 'Pulse period' fields, respectively.

Additionally, for each type of pulse pattern, a time delay may be introduced in the 'Delay' field.

There are 4 output channels that can be utilised. Any generator can be linked to one or more output channels.

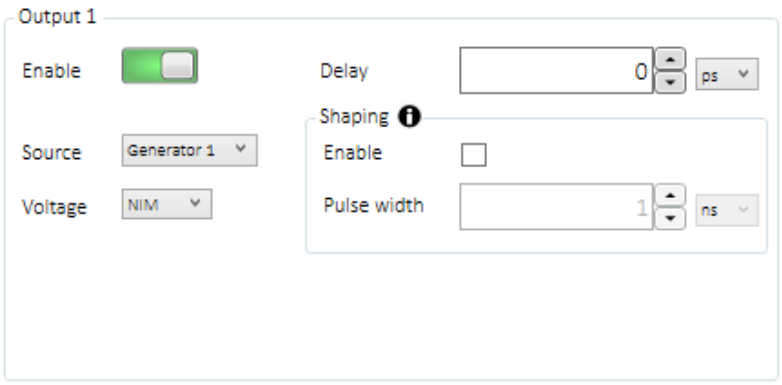


Figure 18: Output channel configuration view

- **Enable:** Flip the 'Enable' toggle switch to activate (green) or deactivate (grey) an output channel.
- **Source:** Select the generator to be used in generating the signal from this output channel for the output a signal from the channel.
- **Voltage:** Select from NIM or TTL as appropriate for the device that is connected to the output channel.
    - Note: NIM signals have a minimum pulse width of 1 ns, while TTL signals have a minimum width of 6 ns.
- **Delay:** Select a delay time between when the pulse or pattern is generated and when the signal is output (up to 1 s with 1 ps precision).
- **Shaping:** Tick enables and set a pulse width to generate a pulse on the rising edge event of the generated pattern instead of a defined pattern.

6.3 Data Acquisition

To perform an acquisition of histogram and/or raw timestamp data:

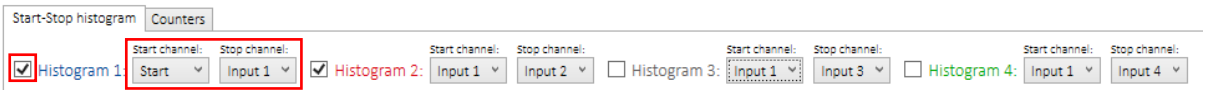
1. Select the pair of channels to be measured, in the 'Start-Stop histogram' view (see Section 6.3.1)
2. Use the Histogram settings view to configure the Histogram time bins (see Section 6.3.2)
3. Use the 'Saving' options to define if and how the data is saved (see Section 6.3.3 and 6.3.4)
4. Use the Acquisition view to prepare and initiate a measurement (see Section 6.3.5).

6.3.1 Channel selection

Both histogram and raw timestamp measurements record the start-stop times between pairs of channels.

Up to four histograms and four sets of timestamps can be recorded simultaneously. At the top of the 'Start-Stop histogram' view in the 'Time-to-digital converter' workspace, select up to four histograms to be measured, and the corresponding pairs of input channels.

If recording raw timestamps, data corresponding to the pairs of input channels specified in the 'Start-Stop histogram' view will be recorded.



6.3.2 Configuring Histogram Time Bins

Use the Histogram settings view to configure the Histogram time bins:

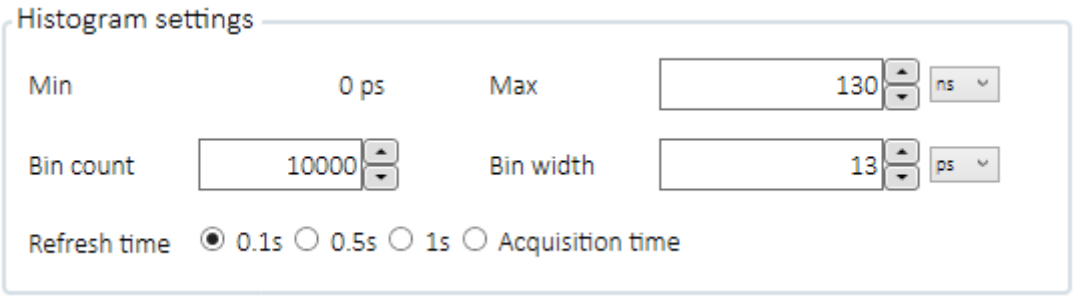


Figure 19: Histogram time bin configuration view

- **Min:** The minimum time bin is fixed at 0 ps in the Time Controller GUI.
- **Max:** Select the value of maximum time bin in the time interval being measured.
  - On changing, the 'Bin count' field will be automatically changed based on the value in the 'Bin width' field.
- **Bin count:** Specify the number of time bins being measured (to a maximum of 16,483).
  - On changing, the 'Max' field will be automatically changed based on the value in the 'Bin width' field.
- **Bin width:** Select the width of each histogram time bin in the time interval being measured.

- On changing, the 'Bin count' field will be automatically changed based on the value in the 'Max' field.

- **Refresh time:** Set the time interval in which the data acquisition refreshes in the Time Controller GUI.

⚠ **If a change in the Max bin, Bin count, or Bin width does not change the 'Bin count' or 'Max bin' field correctly, click down and then up in the right-hand of the field that was changed.**

6.3.3 Saving Data

Data is saved automatically during an acquisition. Use the 'Saving' options to define how the data is saved for both histogram and timestamp data.

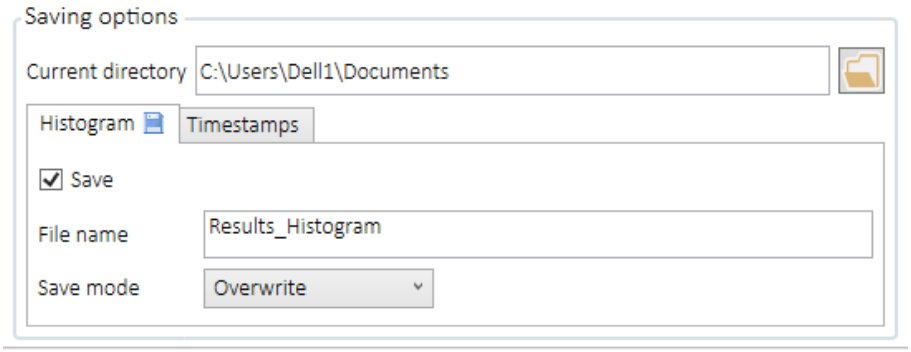


Figure 20: Saving options view

⚠ **Note**: You must choose whether data will be saved prior to beginning an acquisition. It is not possible to save data in the Time Controller GUI after an acquisition is complete, even if the data is plotted in the histogram workspace.

Current directory: Select the folder you wish the measurement results to be saved to.

Histogram / Timestamps:

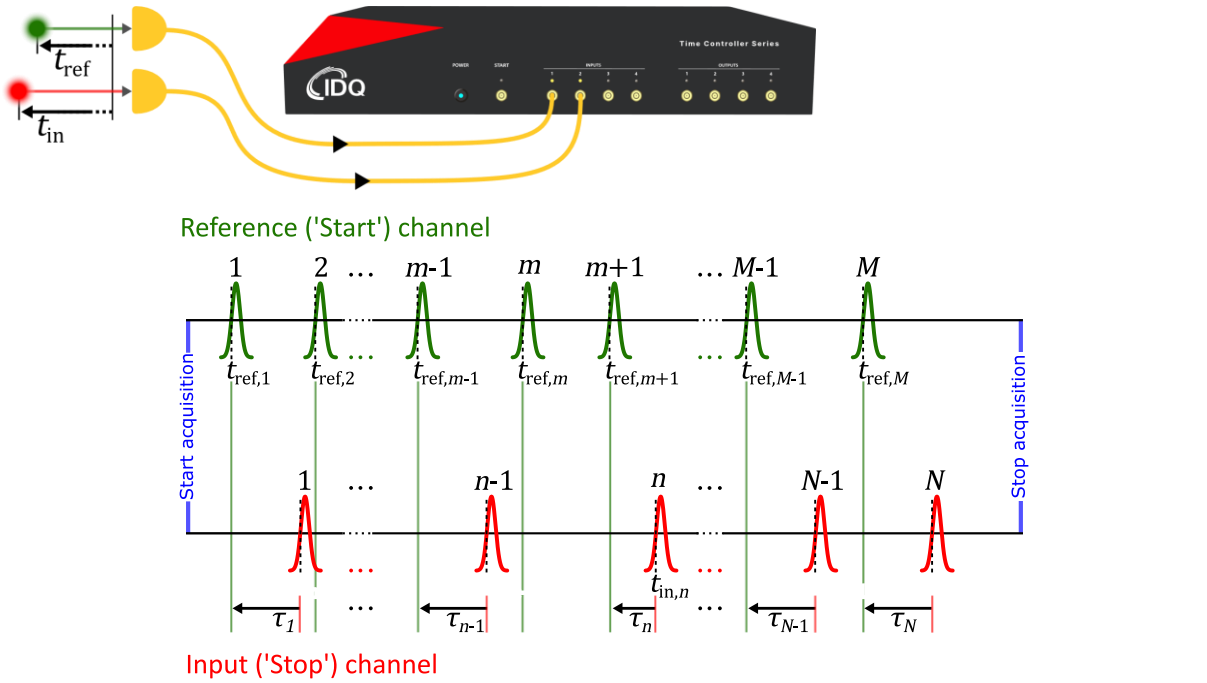
- **Save:** Prior to running the acquisition, to save the data to be collected, select the 'Save' checkbox in the Histogram and/or Timestamps tab as appropriate.
- **Include start index:** (Timestamps only) For each data point, include the number of counts on the reference channel at the time of measurement.
- **File name:** select a base filename for the saved data.
- **Save mode:** Select one of the four choices for save mode:
  - **Overwrite:** This will overwrite any data in the existing data file.
  - **Append:** This will append data to the existing data file.
  - **With Date:** This will add a time & date to the file name and save a new file on each acquisition.
  - **With Counter:** This will add an incremental counter to the file name and save a new file on each acquisition.
- **Format:** (Timestamps only) Select whether to save the timestamp data as ascii text or in uint64 binary format.

6.3.4 Timestamp Data

With the Time Controller Series, users have the option to record the arrival time of every individual detection event incident on an input channel, referred to as 'timestamps', rather than the aggregated data of count rates or histogram time bins, for up to four input channels.

Timestamp data acquisition is again defined in pairs of reference ('start') and input ('stop') channels, where timestamps for up to four channel pairs can be collected simultaneously. Note that histograms can be collected in parallel to these timestamp acquisitions. The user selects these channels as described in Section 6.3.1 – Channel selection, and ensures the 'Save' checkbox (and optionally the 'include start index' checkbox) is selected in the Timestamps tab of the Save options view (see Figure 20).

Note: Timestamps are only recorded if the 'Save' checkbox is selected in the Timestamps tab of the Save options view (see Figure 20), and reference indices will only be recorded if the 'include start index' checkbox is additionally selected.



Timestamp datafile

Row 1:	$\tau_1\ (=t_{in,1}-t_{ref,1})\ ;\ 1$
…	
Row n-1:	$\tau_{n-1}\ (=t_{in,n-1}-t_{ref,m-1})\ ;\ m$-1
Row n:	$\tau_n\ (=t_{in,n}-t_{ref,m+1})\ ;\ m$+1
…	
Row N-1:	$\tau_{N-1}\ (=t_{in,N-1}-t_{ref,M-1})\ ;\ M$-1
Row N:	$\tau_N;\ (=t_{in,N}-t_{ref,M})\ ;\ M$

Figure 21: Diagram of timestamp acquisition for a single reference/'start' (green) and input/'stop' (red) channel pair. Here, a 'timestamp' is recorded as the time difference between an observed input channel pulse (solid red curve) and the most recent reference channel pulse (solid green curve), when and only when a pulse is observed on the input channel. Meanwhile, the Time Controller is also counting how many pulses have occurred on the reference channel, recorded alongside each timestamp as the 'reference index'.

Timestamp data is recorded in pairs of numbers (see Figure 21) , written in binary format (uint64) or directly into a text file:

1. **The timestamp**: the time in picoseconds between a detection event on the input channel (the 'Stop channel' or '2nd channel' in the Start-stop / Coincidence histogram views) and the last detection event on the reference channel (the 'Start channel' or '1st channel' in the Start-stop / Coincidence histogram views). There is one timestamp per input channel detection event. This number serves as the fine 'micro-time', the precise timing information within a given clock cycle / reference period.
2. **The reference index (optional)**: the number of detection events that have occurred on the reference channel, until the latest input channel detection event occurred. This number serves as the coarse 'macro-time', sufficient to reconstruct the fully precise time-tag when paired with a timestamp and precise clock reference signal, or to identify which detection events on different input channels occurred within the same clock cycle / reference period.

Timestamp data for each pair of selected channels is written to a binary file or text file as follows, with up to four files for up to four pairs of selected channels per acquisition:

	Binary format, '*.bin'	**Text format, '*.txt'**
Without start index	<timestamp>	<timestamp>
With start index	<timestamp><index>	<timestamp>;<index>

Table 10: Format of data in Timestamp datafiles

⚠ **Caution: Ensure the number of timestamps processed per second is lower than 10 million, across all channels.** If higher than 10 M events/s, the buffered timestamp events may overflow and cause a conflict in the internal device logic, requiring a manual restart of the Time Controller unit.

⚠ **Note**: If a reference signal is not used or the reference channel receives no signal, the timestamps generated grow until they roll over after 2^{60} picoseconds (approximately two weeks).

⚠ **Note**: To optimize the transfer rate and to avoid data loss, binary format is recommended. For high data transfer rates, also consider the specifications of the host computer.

Figure 22 shows an example of a timestamp datafile. In this example, 1,024,875 timestamps have been recorded, corresponding to 1,024,875 events being registered on the defined input ('stop') channel, and 6,000,832 events being registered on the reference ('start') channel. Note that the timestamp will reset to zero every time there is an event on the reference channel, and thus appears random in this example. The reference index, however, will always increase monotonically, though there may be more or less than one input events between timestamps, so each increment in the reference index may appear random.

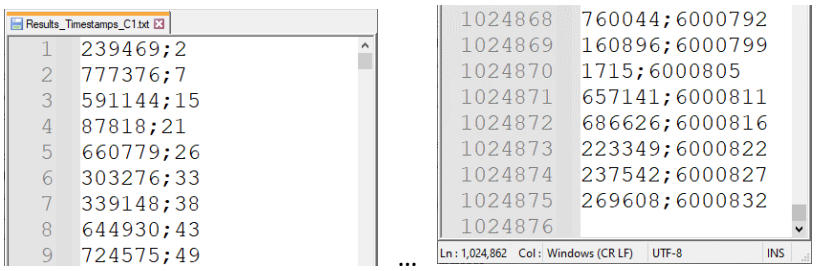


Figure 22: An example timestamp data file, saved in text (.txt) format. Each row represents an individual detection event on a single input channel, where up to four datafiles for up to four sets of input/reference channels can be acquired simultaneously. The number in the left column, before the semicolon, is the timestamp: the time in picoseconds between a detection event on the reference ('start') channel and the input ('stop') channel. The number in the right column, after the semicolon, is the reference index: the number of events that have been registered on the reference channel prior to the timestamp being recorded.

6.3.5 *Initiate Acquisition*

Use the Acquisition view to prepare and initiate a measurement.

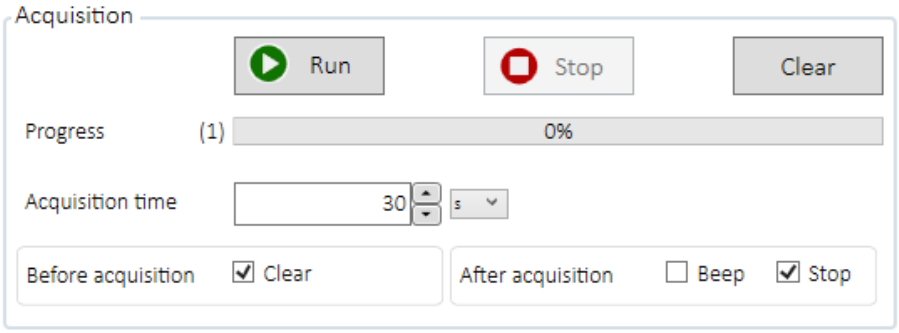


Figure 23: Acquisition configuration view

- **Acquisition time:** Set the duration time of the acquisition.
- **Before acquisition:**
  - Select the Clear checkbox to clear existing data at the start of the next acquisition. Deselect the Clear checkbox to append the next acquisition's data onto the currently visible data.
- **After acquisition:**
  - Select the Beep checkbox to trigger a beep sound from the host computer when the acquisition time has passed.
  - Select the Stop checkbox to stop the acquisition when the acquisition time has passed. Deselect the Stop checkbox to have the acquisition run repeat after each acquisition time until the Stop button is pressed.
- **Run:** Click Run to start an acquisition.
- **Stop:** Click Stop to stop an acquisition.
- **Clear:** While not running acquisition, click Clear to clear the data from a previous acquisition. If running an acquisition, click Clear to restart the acquisition.
- **Progress bar:** View how much of the acquisition has been completed in relation to the Acquisition time.

6.4 Automating use of the Time Controller

In this section, we explore the expanded use of the Time Controller in some common laboratory automation environments.

Avoid alternating between use of the Time Controller software and any programmatic use of the (including the SCPI console).
The Time Controller software only registers a change in a device parameter when the command is issued via the Time Controller GUI. Therefore, changes made outside of the GUI will not be reflected in the GUI, and configuration conflicts may occur.

In cases of significant clashes, the physical Time Controller unit may need to be manually restarted.

6.4.1 SCPI commands

Commands are issued to the Time Controller in the form of text strings adhering to the Standard Commands for Programmable Instruments (SCPI). Refer to Section 9 – "Appendix: SCPI Command Reference" for the full set of SCPI commands needed to operate the Time Controller.

SCPI commands are not case sensitive, but they are often shown with a mixture of upper-case and lower-case characters. Commands can be abbreviated by only sending the upper-case characters.

For example, the command asking for the counts measured on input channel 1

```
INPUt1:COUNter?
```

is the same as

```
INPU1:COUN?
```

and

```
inpu1:coun?
```

Multiple SCPI commands, separated by a semi-colon character, can be sent as a single string. A colon character at the start of the command means the command is interpreted with respect to the root of the commands tree, while no colon means the command refers to the last node in the preceding command.

For example, this command reads the counts measured on input channel 1, and then reads whether that channel is activated:

```
INPUt1:COUNter;:INPUt1:ENABle?
```

which is the same as

```
INPUt1:COUNter;ENABle?
```

6.4.2 LabView VIs

For examples of virtual instruments that can operate the Time Controller from within LabView, refer to the example '.vi' files that can be found on the USB memory stick supplied with the Time Controller device.

6.4.3 Python

The Time Controller relies on the ZMQ library for communication with the host computer. Install it using your Python distribution's command console:

```
> easy_install pyzmq
```

Or

```
> pip install pyzmq
```

Following this, you can then issue SCPI commands within python to interact with your Time Controller. For example:

```
import zmq, socket

# Identify your Time Controller device
IP = '169.254.xx.1xx' # << change this to the IP address of your TC
PORT = 5555
ADDR = f'tcp://{IP}:{PORT}'

# Create zmq socket and connect to the ScpiClient
context = zmq.Context()
timecontroller = context.socket(zmq.REQ)
timecontroller.connect(ADDR)

# Execute SCPI commands on your TC. E.g.:
SCPIcommand = 'INPUt1:COUNter?' # How many counts on input channel 1?
timecontroller.send_string(SCPIcommand)
answer = timecontroller.recv().decode('utf-8')
print(answer)
```

For further information, refer to the example python scripts that can be found on the USB memory stick supplied in the delivery of the Time Controller device.

6.4.4 Data Link Target Service

The Data Link Target (DLT) Service run is responsible for the Time Controller's timestamps reception on the host computer. The DLT binary is installed by the Time Controller GUI setup and can be found in the following directory by default:

```
C:/Program Files/IDQ/Time Controller/packages/ScpiClient
```

Before starting an acquisition, start the DLT by either opening the GUI (which starts the DLT) or run the DLT binary with the following arguments.

```
DataLinkTargetService.exe -f <TS_FOLDER> --logconf <LOGCONF_PATH>
```

The <TS_FOLDER> is the default directory where timestamps should be stored when a relative path is used with the start-save DLT command. The GUI sets it in the My Documents directory.

The <LOGCONF_PATH> is the path to the logging configuration file which is automatically created by the GUI. If you need to create it yourself, use the template located in the same directory as the DLT. Then set the desired path for the DLT log file with the following property.

```
log4cplus.appender.AppenderFile.File=
```

The GUI sets the following log path:

```
<My Documents>/IDQ/Time Controller/<GUI version>/ScpiClient/logs/
DataLinkTargetService.log
```

You don’t need to close the DLT after running a timestamp acquisition, but you will need to restart it to change the default timestamps directory or log path with the arguments described above.

For further information, refer to the Appendix: DLT Command Reference section, and the python or LabVIEW timestamps acquisition example scripts that can be found on the USB memory stick, supplied in the delivery of the Time Controller device.

7 Multi-Device Operation

Under standard operation conditions, a single Time Controller can measure up to four histograms and four sets of timestamps independently, from up to five input channels. In this section, we describe how you can connect and operate multiple Time Controllers in series, to measure time-resolved correlations between over 64 input channels concurrently.

⚠ **Avoid alternating between use of the Time Controller software and any programmatic use of the Time Controller (such as the scripts for multi-device acquisition detailed in this Chapter).**
The Time Controller software only registers a change in a device parameter when the command is issued via the Time Controller GUI. Therefore, changes made outside of the GUI will not be reflected in the GUI, and configuration conflicts may occur.

In cases of significant clashes, the physical Time Controller unit may need to be manually restarted.

7.1 Up-to-date Software

To operate multiple Time Controllers in the manner described in this chapter, ensure that the firmware of the Time Controllers and the software on the host computer has been updated to the versions from release 1.7.0 or later.

Follow the steps in Section 4.3.2 – Time Controller Firmware to update the firmware of all your Time Controller devices, where the latest version of the firmware can be found on our website (see Section 3.1.6 – Software)

7.2 Supporting Scripts

Multi-device operation of your Time Controllers is mediated through a set of supporting scripts, which can be found on our website (see Section 3.1.6 – Software).

These include the scripts timestamp_acquisition_multi_tc.py and config.json, and the folder of supporting functions multi_tc_acquisition. Ensure that these scripts and folder are copied to the same directory on the host computer. To operate these scripts, ensure that you have Python release 3.4.0 or later installed (available at https://www.python.org/downloads/).

To operate a multi-device acquisition, a command line acquisition script operates in concert with an acquisition configuration file, as detailed below.

7.2.1 Command Line Acquisition Script

The timestamp_acquisition_multi_tc.py script provides a command line interface with which to perform multi-device acquisitions. See Section 7.5 – Execute Multi-Device Acquisition for more information on configuring and using the timestamp_acquisition_multi_tc.py acquisition command.

7.2.2 Acquisition Configuration File

The timestamp_acquisition_multi_tc.py command requires an underlying configuration file, to instruct the multi-device arrangement on which measurements are being performed by which channels on each Time Controller device. An example configuration script, config.json, has been included with the multi-device operation scripts.

The configuration file is used to specify:

- The identifying names and IP addresses for the Time Controller devices.
- The position of each Time Controller device in the multi-level 'tree' layout.
- The input channel settings (threshold voltage, detection edge, and delay) for each input channel on each Time Controller device.
- The type of acquisition (histogram and/or timestamp), acquisition settings, and start-stop channel configuration.

See Section 7.4 – Set up the Acquisition Configuration File for more information on setting up the acquisition configuration file.

7.3 Device Layout

To synchronize the acquisition of multiple Time Controllers, the devices are connected as a multi-level 'tree'. Ideally, each Time Controller will be connected to the same host computer, but acquisition is also possible if all Time Controllers are on the same local area network.

Operating the Time Controllers on a local area network may reduce the maximum rate of timestamps that can be collected and could lead to mid-acquisition device communication issues if other network traffic is significant.

The first Time Controller and root of the tree is called the 'master'. This Time Controller shares its clock frequency with all the other devices of the layout, called 'agents', and controls the beginning of the acquisition.

The master device can have up to three Time Controllers connected immediately beneath him, which makes for the first level of the tree. Apart from the master, which can only have three agents, all other Time Controllers in the tree layout can have from zero to four agents each.

Try to use as few levels as possible in the multi-device arrangement. Upon starting each acquisition, the small timing uncertainty in the Time Controller's start pulse (40 ps rms jitter, see Section 5.3 – I/O specifications) results in a small but random relative shift in the acquisition start time as seen by each Time Controller, an effect which increases for each subsequent level. This start-time shift does not affect the timing resolution of the data being recorded.

All devices, except for those on the lowest level of the multi-device 'tree', require the MASTER or TCSPC-4OUT licenses (see Section 3.1.6 –"Software"), as operation of multiple Time Controllers as described in this chapter relies on pulses generated by the output channels.

Figure 24, below, illustrates how to connect a two-level layout with 4 Time Controllers.

- The SYNC connectors on the rear of each device are connected in series, beginning with the master (blue wire), to maintain synchronicity of the internal counters over long times. Note that the SYNC connectors will always be connected in a linear chain in this way, even with additional levels.
- Each of the master's outputs is connected to each of the agents' START input channels (green wire), where each output will send a simultaneous pulse to initialize the start of a multi-device acquisition, including the master's own START channel.

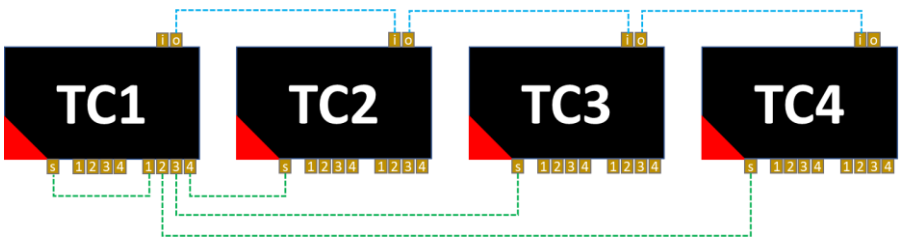


Figure 24: Two-level layout with four Time Controllers. Green wires show electrical connections between the pulse generator outputs and the Time Controller START input channels, while the blue wires show electrical connections between the SYNC connectors of each Time Controller.

7.4 Set up the Acquisition Configuration File

The acquisition configuration file (see Section 7.2.2 – Acquisition Configuration File), as exemplified in the example config.json, instructs the multi-device arrangement on which measurements are being performed by which channels on each Time Controller device.

7.4.1 Root

The root level of the configuration file is an object with the following properties, structured in the following way:

```
{
        "high_resolution": <resolution setting>,
        "devices":
        {
                "device name #1": { <device settings> },
                "device name #2": { <device settings> },
                ...
        },
        "layout":
        {
                <layout settings>
        }
}
```

- "high_resolution":
  Set the resolution mode the devices operate in.
  - High resolution: set *<resolution setting>* to true
  - High speed: set *<resolution setting>* to false

  ⚠ Acquisition in high resolution mode requires the MASTER-HR or TCSPC-HR licenses (see Section 3.1.6 – Software).

- "devices" (see Section 7.4.2 – Device settings)
  Each property of this object defines the configuration of a Time Controller in the multi-device setup. The property name defines the alias of each Time Controller, freely defined here by the user. The device settings for each Time Controller specify the IP address for the device, which measurements the device will perform on which channels, and the input channel settings for each channel being utilised.
- "layout" (see Section 7.4.3 – Layout settings)
  Recursive structure which defines the physical arrangement of the multi-device arrangement.

7.4.2 Device settings

Each property of the "devices" object defines the configuration of a Time Controller in the multi-device setup. The name of each Time Controller (e.g. "device name #1") can be freely defined here by the user. The following properties can be defined for each Time Controller:

- "ip": The given Time Controller's IP address.
- "timestamps": Object specifying the timestamps to be acquired on the given Time Controller (see Section 7.4.2.2 – Timestamps).
- "histogram": Object specifying the histograms to be acquired on the given Time Controller (see Section 7.4.2.2 – Histograms).
- "inputs": Object specifying the settings for each input channel on the given Time Controller (see Section 7.4.2.1 — Inputs).

```
"devices":
{
    "device name #1":
    {
        "ip": <IP address>,
        "timestamps": { <timestamp settings> },
        "histograms": { <histogram settings> },
        "inputs": { <input settings> }
    }
   ...
}
```

7.4.2.1 Inputs

Each property of the "inputs" object refers to the input channel number, between 1 and 4. In a multi-device Timestamps acquisition, for each input channel on the given Time Controller, the following properties can be specified:

- "threshold" (float): Input threshold in volts.
- "edge" (string): Either "falling" or "rising".
- "delay" (integer): Delay in picoseconds.

```
"inputs":
{
    "1":
    {
        "threshold": <IP address>,
        "edge": { <timestamp settings> },
        "delay": { <delay> }
    }
    "2": { ... },
    "3": { ... },
    "4": { ... }
}
```

7.4.2.2 Timestamps

The "timestamps" object specifies the sets of timestamps to be measured on the given Time Controller, where the following properties can be specified:

- "format": Either "bin" or "acsii" (see Section 6.3.4 – Timestamp Data).
- "acquisitions": List of acquisition start/stop input pairs (up to 4 pairs).
    - For example, the following setting specifies collection of two sets of timestamps:

      ```
      "acquisitions": [[0,1],[1,2]]
      ```

        - The first timestamps have input channel 1 as the input (stop) signal, and the input START channel (i.e. the start of the multi-device acquisition) as the reference (start) signal.
        - The second timestamps have input channel 2 as the input (stop) signal, and the input channel 1 as the reference (start) signal.
    - Apart from channel 0 (START), all input channels which are specified in the acquisition pairs must be defined in the inputs section of the device.
- "with_ref_index": (optional, default: false) true or false, timestamps are paired with reference indices (see Section 6.3.4 – Timestamp Data).

```
"timestamps":
{
    "format": { <datafile format> },
    "acquisitions": { <acquisition settings> }
    "with_ref_index": <reference index setting>
}
```

Caution: Ensure the number of timestamps processed per second is lower than 10 million, summed across all channels on all devices. If higher than 10 M events/s, the buffered timestamp events may overflow and cause a conflict in the internal device logic, requiring a manual restart of the Time Controller unit.

7.4.2.3 Histograms

The "histograms" object specifies the start-stop histograms to be measured on the given Time Controller, where the following properties can be specified:

- "format": File format of the histogram data to be saved to, either "csv" or "pdf".
- "acquisitions": List of acquisition start/stop input pairs (up to 4 pairs).
    - For example, this setting specifies collection of two histograms:

      ```
      "acquisitions": [[3,1],[4,2]]
      ```

        - Histogram 1 has input channel 1 as the input (stop) signal, and the input channel 3 as the reference (start) signal.
        - Histogram 2 has input channel 2 as the input (stop) signal, and the input channel 4 as the reference (start) signal.
- "bin_width": Width of the histogram time bins in picoseconds.
    - Currently, the maximum number of time bins (16’384) are recorded by default in a multi-device acquisition.

```
"histograms":
{
    "format": { <format> },
    "acquisitions": { <channel pairs setting> },
    "bin_width": { <histogram bin width> }
}
```

7.4.3 Layout settings

The "layout" object is a recursive structure which defines the physical arrangement of the multi-device arrangement. Properties of this object are specified in the following way:

- "device": Name of the given Time Controller (from the alias defined in the "devices" object, see Section 7.4.2 – Device settings).
- "wire_latency": Expected latency in picoseconds of the wire connecting the device to its master (green wires on the Figure 24 and Figure 25). The latency is around 30 picoseconds per 1cm of wire length.
- "agents": Each property of this object defines another layout node (i.e. the connected Time Controller, its wire latency, and agents). The name of the property refers to the input on which the sub-node is connected.

The configuration below (Figure 25) defines an example three-level layout.

```
"layout": {
  "device": "tc1",
  "wire_latency": 1450,
  "agents": {
    "2": {
      "device": "tc2",
      "wire_latency": 1450
    },
    "3": {
      "device": "tc3",
      "wire_latency": 1450,
      "agents": {
        "1": {
          "device": "tc5",
          "wire_latency": 1450
        }
      }
    },
    "4": {
      "device": "tc4",
      "wire_latency": 1450
    }
}
```

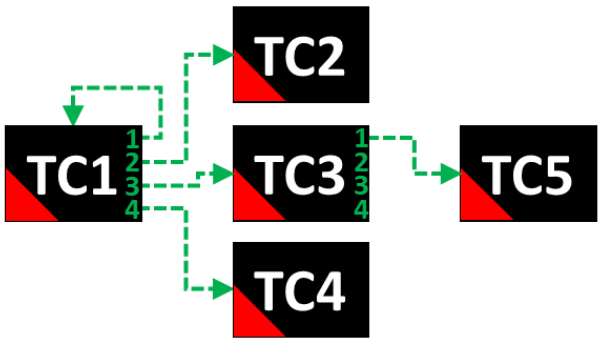


Figure 25: Three-level layout configuration corresponding to the "layout" example specified to the left.

7.5 Execute Multi-Device Acquisition

As a precaution, restart all Time Controllers before you run the multi-device acquisition.
The Time Controller calibration is altered when:

- It loses its SYNC signal (either because the IN cable is disconnected or when the Time Controller which provides the SYNC signal is turned off).
- Its configuration is switched between an external SYNC to the internal SYNC.
- At this point, the device needs to be restarted to calibrate itself properly again.

With an acquisition configuration file correctly prepared (see Section 7.4 – Set up the Acquisition Configuration File), the Time Controller software and firmware updated as appropriate (see Section 7.1 – Up-to-date Software), and the supporting scripts stored on the host computer (see Section 7.2 – Supporting Scripts) it is now possible to perform multi-device acquisition using the timestamp_acquisition_multi_tc.py script.

The acquisition is executed through the timestamp_acquisition_multi_tc.py script in a command line interface. Open any command line console (such as cmd.exe) in the script's directory and run the following command to print the available options, also detailed here below:

```
python3 timestamp_acquisition_multi_tc.py --help
```

or

```
py timestamp_acquisition_multi_tc.py --help
```

```
C:\Users\<user>> cd C:\Users\<multi-tc script dir>
C:\Users\<multi-tc script dir>>py timestamp_acquisition_multi_tc.py --help

usage: timestamp_acquisition_multi_tc.py [-h] [--conf file] [--datalink-dir
path] [--output-dir path] [--duration seconds] [--log path] [-v] [-n N]

optional arguments:
  -h, --help            show this help message and exit
  --conf file           acquisition description file (default: config.json)
  --datalink-dir path   DataLinkTargetService.exe folder
  --output-dir path     output folder
  --duration seconds    acquisition duration (default: 5)
  --log path            log file (default: timestamp_acquisition_multi_tc.log)
  -v, --verbose
  -n N, --repeat N      repeat measurements N times}
```

7.5.1 Script Options

The following options are available for the timestamp_acquisition_multi_tc.py command:

`--conf <FILE>`
: Specify the configuration file to be used (with <*FILE*> being its path), see Section 7.4 – Set up the Acquisition Configuration File.

`--output-dir <DATA_PATH>`
: Specify the path to the directory <*DATA_PATH*> where the acquisition data files are to be saved (by default in the script directory).

`--duration <DURATION>`
: Specify the acquisition time <*DURATION*> in seconds.

`--log <LOG_PATH>`
: Specify the acquisition log directory <*LOG_PATH*> (by default in the script directory).

`-n <N>`
: Specify the number <*N*> repetitions of the configured acquisition, which are then stored in subdirectories (under the output directory) numbered from 1 to N.

`-v`
: Tell the script to run in verbose mode.

7.5.2 Execution example

The following execution of `timestamp_acquisition_multi_tc.py` script will:

- Prepare to perform the measurements in the multi-device configuration specified in the `config.json` file,
- Run five repetitions of the specified acquisition,
- Each repetition of the acquisition will last for one hour (3'600 seconds),
- Store data files in `C:\Temp\acquisitions\<acquisition number 1-5>`, and
- Print each command sent to the Time Controllers and the DataLinkTargetService instance in the console.

```
C:\Users\<multi-tc script dir>>py timestamp_acquisition_multi_tc.py --conf
config.json --duration 3600 -n 5 -v --output-dir "C:\Temp\acquisitions_example"
```

8 Time Controller Configuration

The following section is for users who are interested in advanced operation of the Time Controller device.

The Time Controller is programmed by sending text commands to it and receiving data back though the ZMQ (Zero Message Queue) protocol. This is supported by most programming languages and environments, for example Python, LabView, MATLAB, C, C++.

To achieve high throughput and low latency, the Time Controller performs several of its functions in hardware blocks within the FPGA. These can be configured, and the signal can be routed across these blocks through text commands.

The GUI contains a console tab where the user can try out the different commands and read the results back.

To program the Time Controller, you need a good understanding of its physical and logical architectures, described below.

8.1 Physical architecture

The Time Controller's physical architecture consists of an FPGA and the connections between it and different element. A simplified overview of this is shown in Figure 26.

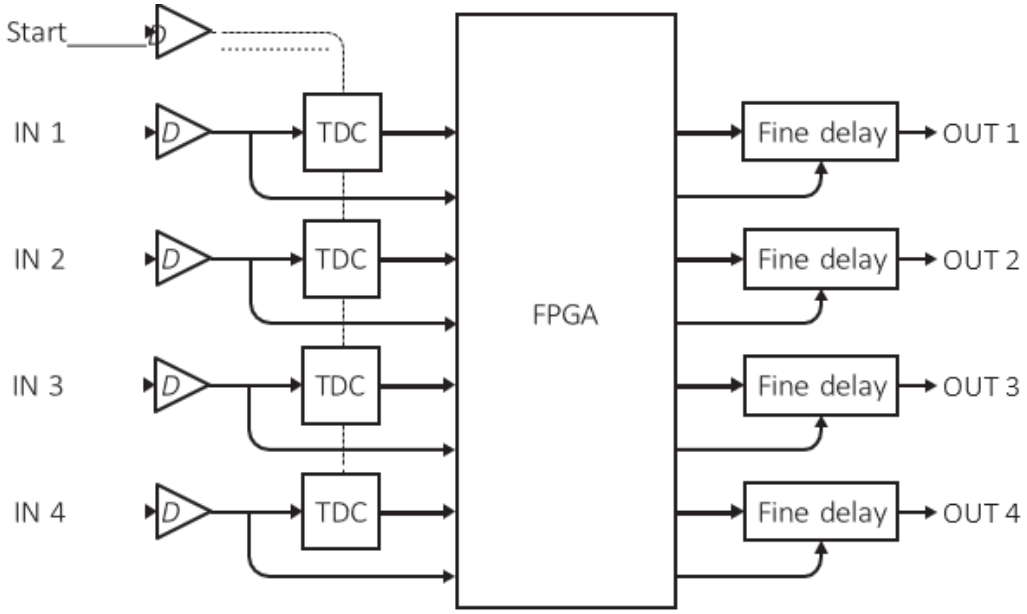


Figure 26: Simplified physical design of the Time Controller. The triangles marked "D" are discriminators. "TDC" is time-to-digital converters.

Each input consists of a discriminator followed by a Time-to-Digital converter chip (TDC). The TDC can be optionally bypassed, with input signals sent directly to the FPGA. The TDC measures the arrival time of pulses with greater precision and digital resolution than direct FPGA measurements, but at a reduced maximum count rate (see Section 5.3.1 – Start channel and Input channels 1 – 4). For the outputs, the FPGA generates signals that have 100 ps time resolution, with 28 ps jitter (see Section 5.3.2 – Output channels 1 – 4) . The external circuits (TDCs and delay generators) only handle the signal over a very short time (< 1 ns). Larger time scales are fully managed by the FPGA.

A start input port signal can be used to set the zero-time reference of the device. If in High Resolution mode, and an ID900 Time Controller is being operated, make sure to use one of the input channels 1 to 4 as a reference, as the Start channel will be disabled. It is also necessary to use a Sync divider for a reference signal frequency above 25 Mcps. It is typically used to connect to the reference pulse of a laser (e.g. 80MHz), or the pulse-per-second (pps) signal from GPS. This signal can also be provided by an internal signal of the Time Controller. Nevertheless, it is strongly recommended to use an external reference when using the device in HR mode. If no signal is received on this channel for more than 2^{60} ps (2 weeks), the device's internal counters will cycle.

All components are synchronously clocked by a precision quartz clock which ensures a jitter < 2 ps. The clock input and output at the back allow for the Time Controller to be synchronized to other

devices, such as an external FPGA, a GPS receiver, an oscilloscope, or an atomic clock. Device-to-device synchronization accuracy is better than 2ps.

8.2 Logical Architecture

The Time Controller's logical architecture consists of the logical blocks that are created in hardware within the FPGA. There are 6 different block types:

- Input
- Output
- Generator
- Combiner
- Histogram
- Raw

Each of these blocks process signals in real time. This architecture is linear and split into levels, and timestamps are processed from left to right.

The default configuration of the blocks and their levels are shown below in Figure 27.

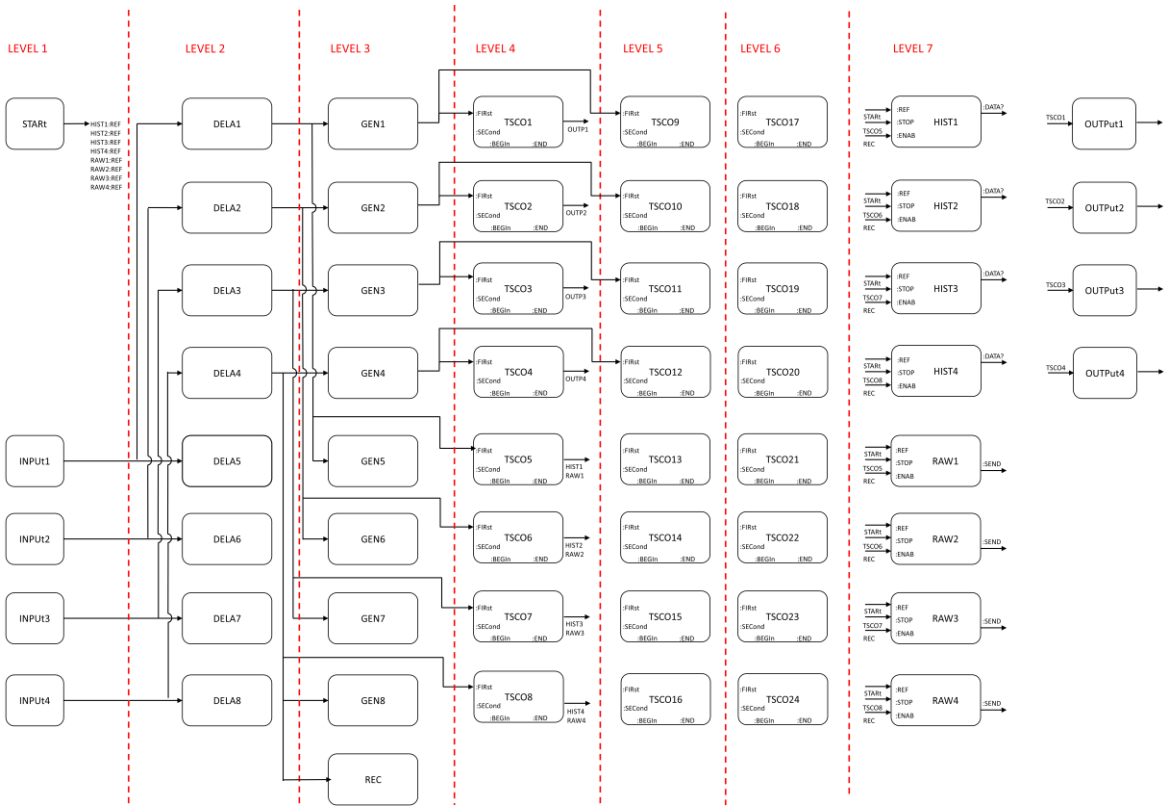


Figure 27: Default Configuration and levels of the Time Controller blocks

8.2.1 Logical Blocks

8.2.1.1 Start (STAR)

There is one start block.

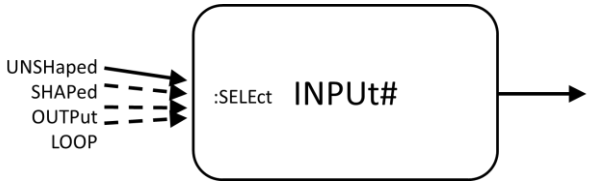
The STARt block receives the signal from the START channel. The signal can be transmitted as it is to the next block (UNSHaped) or modified to be a short pulse (ID900: 5ns, ID1000: 1.2ns) corresponding to the event (SHAPed).

The SHAPed mode is available on the ID900 and the second generation of the ID1000 (HW board version B1 and above). Be aware that the use of the shaper adds a sub-nanosecond delay to the input.

The STARt block is also able to receive a signal generated internally (from another block) by selecting LOOP.

8.2.1.2 Input (INPU)

There are four input blocks, labelled from 1 to 4.



The INPUt block receives the signal from its corresponding input channel. The signal can be transmitted as it is to the next block (UNSHaped) or modified to be a short pulse (ID900: 5ns, ID1000: 1.2ns) corresponding to the event (SHAPed).

The SHAPed mode is available on the ID900 and the second generation of the ID1000 (HW board version B1 and above). Be aware that the use of the shaper adds a sub-nanosecond delay to the input.

The INPUt block is also able to receive a signal generated internally (from another block) by selecting LOOP or can receive the signal from the output of the same index. The mode can be switched between high resolution (HIRES) or high speed (LOWRES).

8.2.1.3 Delay (DELA)

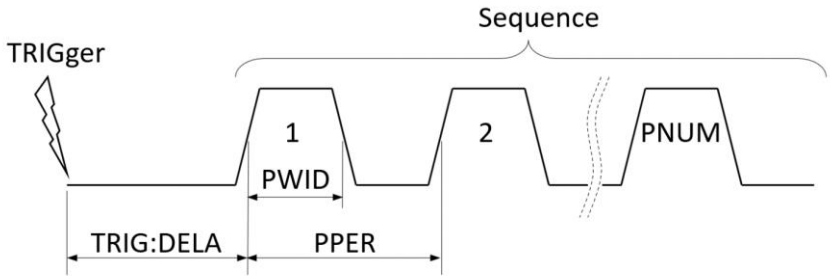
Signals from INPUt blocks are fed through a DELAy block before further processing.

Delay the linked signal by a user-configurable value.

8.2.1.4 Generator (GEN)

Generate a sequence of pulses within the FPGA, defined by the following configurable parameters:

- PNUMber: The number of pulses of the sequence.
- PWIDth: The width (in picoseconds) of each pulse.
- PPERiod: The period between the rising edge of each pulse.



The Generator block operates by transitioning between 4 stages of its state machine (Figure 28).

Stage	Description	Transitions condition	Next Stage
IDLE	Generator is disabled	Enable the generator block	WAITing
WAITing	Ready to play on demand	Manually start to play the sequence	PLAYing
		Manually arm the trigger	ARMed
		Trigger arming mode set as AUTO	ARMed
ARMed	Ready to play when triggered or on demand	Trigger signal received	PLAYing
		Manually start to play the sequence	PLAYing
		Manually disarm the trigger	WAITing
PLAYing	Sequence is being generated	Sequence ends	WAITing
		Manually stop to play the sequence	WAITing

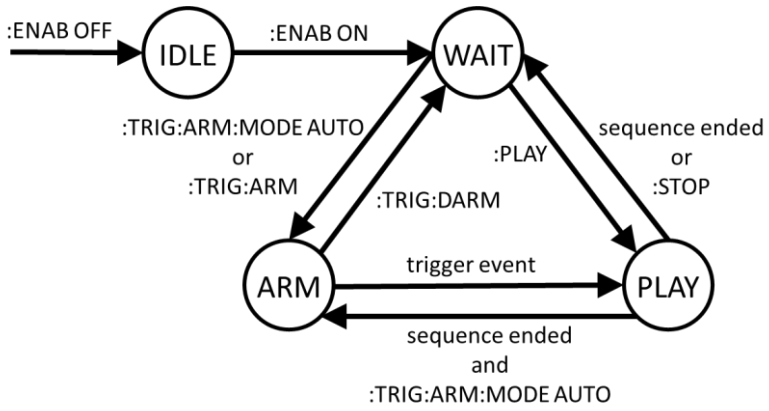


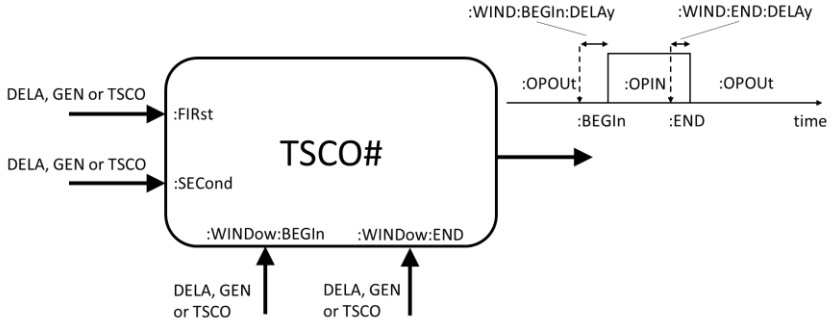
Figure 28: Generator state mechanism

8.2.1.5 Record (REC)

The RECord block is a special case of a Generator block, which work exactly as the other 8 GENerators, with two differences:

1. The RECord block is linked to the HIST and RAW enable link, to control their acquisition time.
2. The command set includes two additional commands (section 9.2.7).

8.2.1.6 Combiner (TSCO)



This consists of four linkable block inputs:

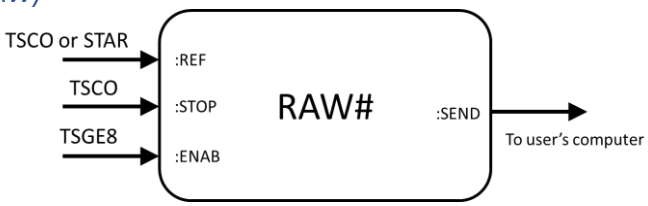
- FIRst and SECond are the two main block inputs. The output of the TSCO gives the result of a logical operation between these two ports. The available logical operations are AND, OR, ONLYFIR (transmit only the data coming to FIRst), ONLYSEC (transmit only the data coming to SECond) and MUTE (nothing comes out). These 2 ports can be connected to any blocks from level n-1 and n-2.
- BEGIn and END are the two block inputs defining the window over which the TSCO operates on FIRst and SECond. The window begins when a signal arrives in the BEGIn port and ends when a signal arrives in the END port. Both beginning and end of the windows can be delayed by a desired value. OPIN defines the logical operation inside the windows and OPOUT defines the operation outside the window. These 2 ports can be connected to any blocks from level n-1 and n-2.

8.2.1.7 Histogram (HIST)

Entails three linkable block inputs:

- :REF is the reference of the histogram, meaning every timestamp is calculated with respect to the last received signal on REF. If the :REF is not connected or does not receive any signal, the default reference is the beginning of the acquisition.
- :STOP receives the timestamps to be calculated. The value is determined as [STOP-REF] and then used to build the histogram.
- :ENAB determines when the acquisition of data begins and ends. It is controlled by the RECord generator.
- HISTO:DATA? give back the histogram data computed directly on board. The bin size and histogram bounds can be set.

8.2.1.8 RAW data (RAW)

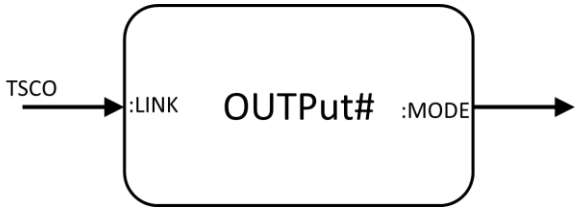


Consist of three linkable block inputs:

- :REF is the reference of the histogram, meaning every timestamp is calculated with respect to the last received signal on REF. If the :REF is not connected or does not receive any signal, the default reference is the beginning of the acquisition.
- :STOP receives the timestamps to be calculated. The value is determined as [STOP-REF] and then saved in a file.
- :ENAB determines when the acquisition of data begins and ends. It is controlled by the RECord generator.
- RAW:SEND enables the sending of raw timestamp data to the computer.

8.2.1.9 Output (OUTP)

Transmits the signal received from the corresponding (same index) source block to the physical output port of the Time Controller.



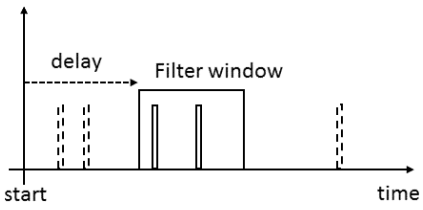
The Output block can also be used to delay and ”shape" the linked signal through user-configurable DELAy and PULSe parameters. When the PULSe mode is enabled, a rising edge event at the input of the block will trigger a pulse of the width specified by the parameter PULSe:WIDTh.

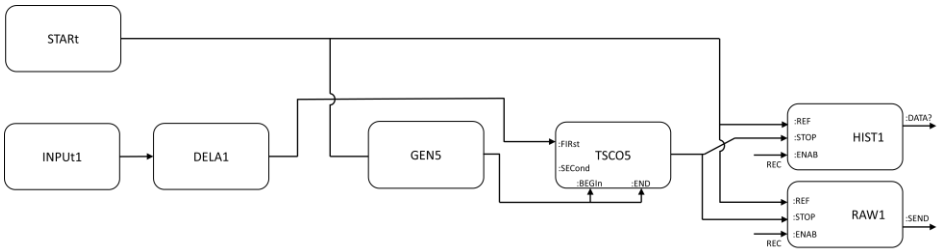
8.3 Configuration examples

To realize the following configurations, text files with the list of SCPI command is included in the release package. These files can be browsed in the SCPI console in the GUI or used in an external script (Python, LabView...).

8.3.1 Start referenced timestamp filter

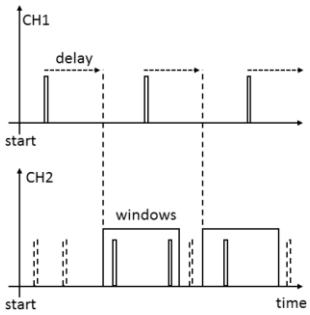
The user only cares about events that happens within a time window of a given width with a given delay with respect to the Start signal.

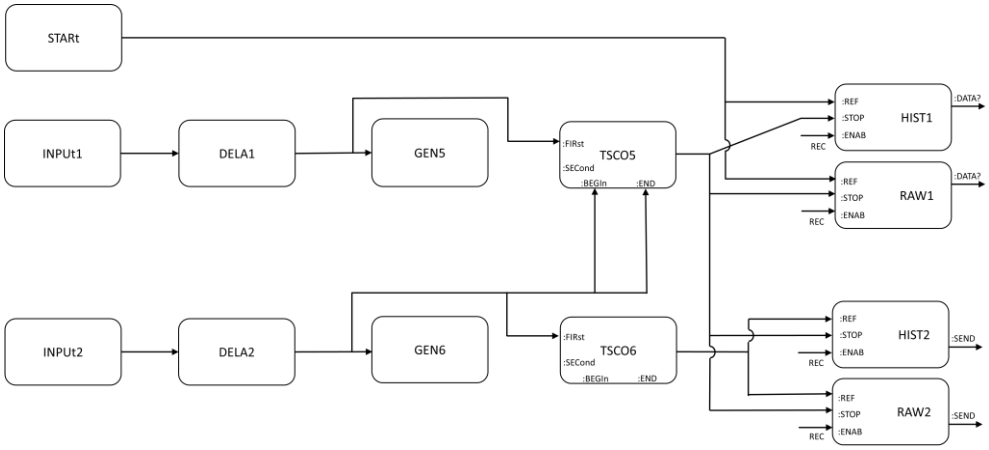




8.3.2 Coincidence filter on board

The user only cares about events that happens within a time window of a given width with a given delay with respect to another input signal. The user wants to have both the time difference between the 2 channels (registered by RAW2) but also the timestamp value with respect to the STARt signal (registered on RAW1).





8.3.3 Synchronized delay generation

The user wants to generate pulses with the outputs of the Time Controller that operates at the same frequency but with a different delay. From version 1.2 it is possible to have the same generator on all 4 output stages and chose to set the delay on each output stage up to 4ms.

8.3.4 Deadtime

The user wants to apply a deadtime on a measured signal. From version 1.7.0, it is possible to use the generators to implement this feature. The generator must be configured such that it is triggered by the measured signal (GEN#:TRIG:LINK <signal source>;ARM:MODE AUTO) and generate a single pulse (GEN#:PNUM 1) that has a period equal to the desired deadtime.

This way, when the generator is triggered, it will generate a pulse and ignore any other trigger for the duration of the pulse period, creating the expected deadtime.

The minimum deadtime with this method is 4ns.

An alternative method to create a fixed deadtime without using is to enable the input shaper (see sections 8.2.1.1 and 8.2.1.2).

8.4 Time Controller Configuration Editor

The Time Controller Configuration Editor application (Figure 29: Configuration Editor) provides a graphical representation of the Time Controller internal configuration.

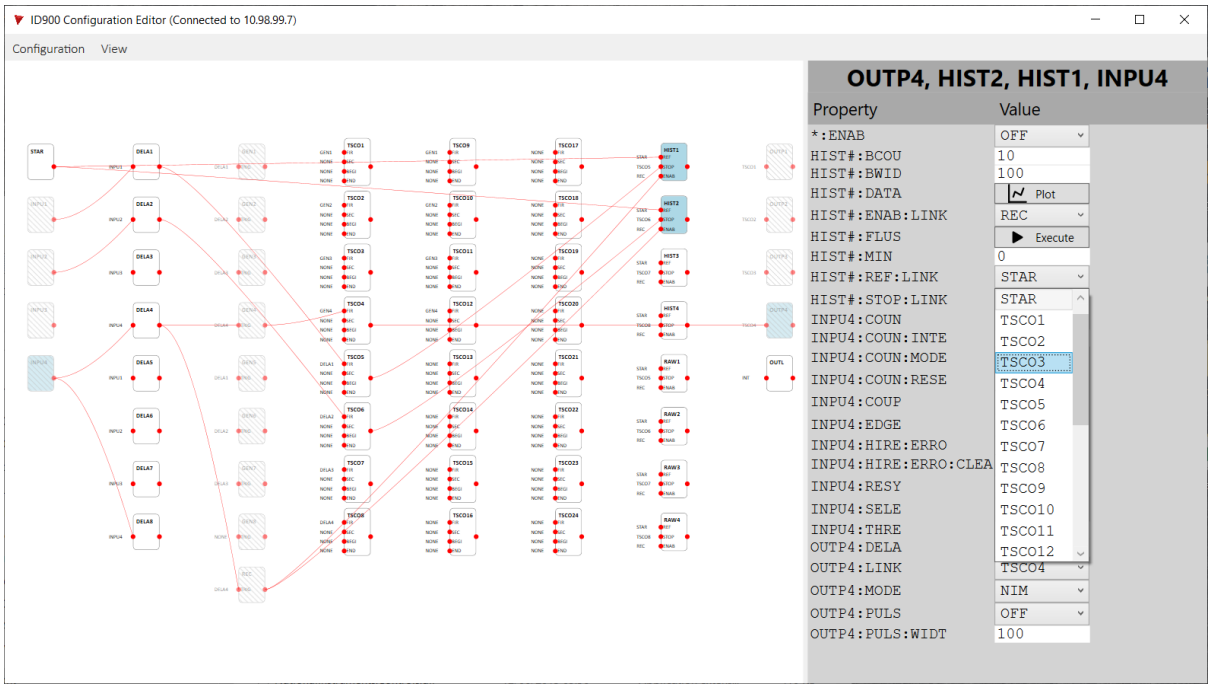


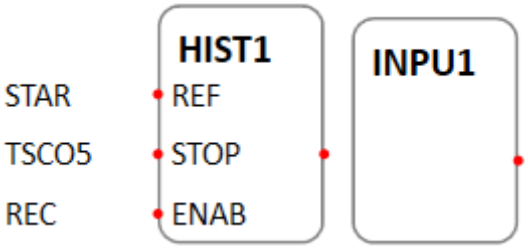
Figure 29: Configuration Editor

Block visualization: Blocks are represented by squares with the available LINK (e.g. REF, STOP, ENAB). The name of the block connected to each LINK is displayed outside the block in front of the corresponding LINK.

- Selected blocks appear in blue:

- Disabled blocks (:ENAB OFF property) are hatched:

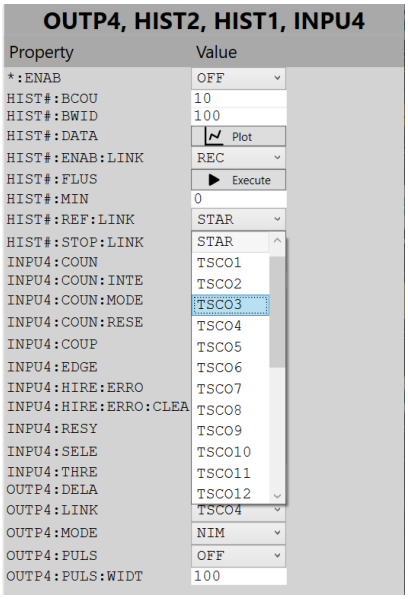
- Enabled blocks (unselected) appear normally:



Select or hover over one or more blocks with the mouse to visualize its linked blocks. These appear as red lines linking one block to another. See Figure 29: Configuration Editor.

Block configuration: The characteristics of the selected blocks are displayed on the right side of the window:

This panel allows to display and edit the value of the block(s) properties.



When multiple blocks are selected, same shared properties between blocks are grouped together. For instance:

- HIST# : shared commands between the HIST blocks.
- *:ENAB : command “ENAB” of INPU4 and OUTP4.

This grouping permits fast edition of control of multiple blocks at the same time (e.g. the selection of TSCO3 here, would change the REFerence of both histogram 1 and 2).

When the properties grouped together hold different values, they are marked as “<MIXED>” or are empty for multiple selection boxes.

This view also allows to execute commands, such as flushing the histograms or plot them:

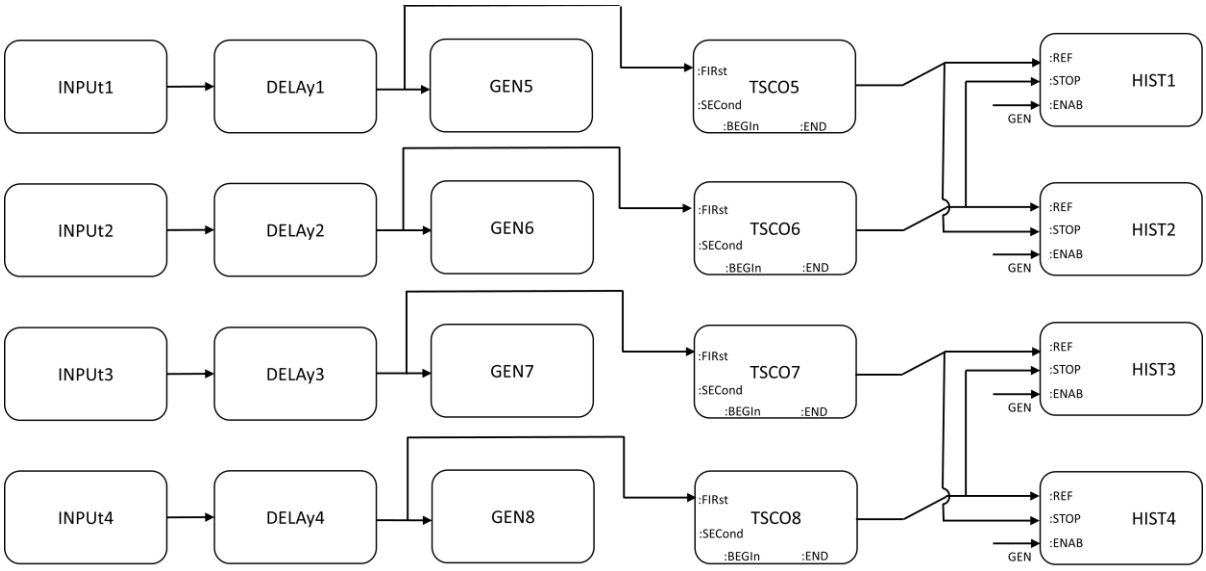
Navigation: When the auto-zoom is enabled (with the bottom left button activated), all blocks automatically fit on the screen. When the auto-zoom is disabled, it is possible to manually zoom in or out by holding CTRL and using the mouse wheel.

Load or save a configuration: Use the Save to file or Load from file buttons to load or save a configuration. Some example configurations are offered in the package release.

8.5 Coincidence histogram configuration

The Coincidence tab in the Time Controller software allows you to do coincidence histogram between 2 channels. This mainly consists of a change of configuration in the SCPI blocks. The configuration is changed when an acquisition is Run and the user switches between a coincidence histogram and start-stop histogram.

The coincidence histogram configuration is shown in the scheme below.



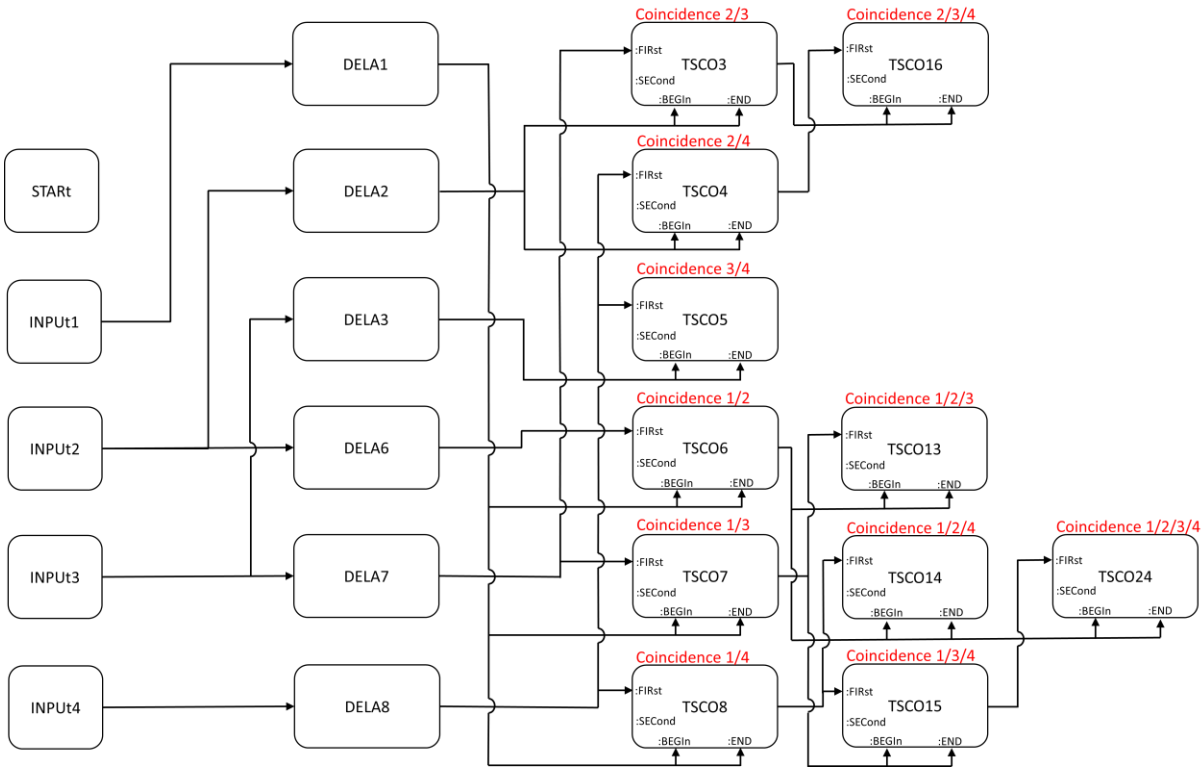
Only the LINK connection of the HISTO and RAW blocks changes.

Raw data can also be extracted. In that case, file labelled 1 will give the values of Stop2-Stop1 while the file labelled 2 gives the value of Stop1-Stop2. File labelled 3 will give the values of Stop4-Stop3 while the file labelled 4 gives the values of Stop3-Stop4. The same logic applies for the saved .csv file of the histogram.

8.6 Coincident Counter measurement configuration

The Counters tab in the Time Controller software (see Section 6.1.2.2) allows you to display the count rates for individual input channels, as well as coincidences, triple-coincidences, and fourfold-coincidences.

In the Coincidence histogram tab, the configuration pushed to the Time Controller when an acquisition is run is:



These counters are displayed on bar indicators with the counters value on top (the Counters rounding controls how the displayed value is rounded) and over time through the bottom graph (the Counters history settings control its timespan).

The counters are refreshed by running an acquisition in this tab. Uncheck the Clear and Stop checkbox and increase the acquisition time to display a continuous and smooth graph of counters over time.

9 Appendix: SCPI Command Reference

Time Controller commands are written in the standard SCPI syntax used throughout scientific instrumentation. This syntax follows these rules:

- It is non-case sensitive, e.g. INPUT1:ENABLE, input1:enable, INPUt1:ENABle are all OK.
- It is structured according to a command tree, with each level separated by a colon, e.g. INPUT1:ENABLE and INPUT1:EDGE refer to the same input.
- It has an optional shorthand notation (the part which is in capitals in the manual), e.g. INPU1:ENAB is the same as INPUt1:ENABLe.
- It can be queried by appending a question mark: INPUt1:ENABle? will return ON or OFF, depending on the input status.
- The commands have a default value that is underlined in this manual, e.g. INPUt1:ENABle and INPUt1:ENABle ON are equivalent.
- The commands sometimes have a numeric suffix to refer to different channels or blocks, e.g. INPUt1, INPUt2 etc. This is indicated by the hash # symbol in the documentation, i.e. INPUt# where # typically takes values 1–4.
- The commands may take an input with unit appended, e.g. INPUt1:THREshold 1 is equivalent to INPUt1:THREshold 1000mV or INPUt1:THREshold 1V.
- The time base unit (TB) is 1ps. You can use for instance GTB for giga-time-base unit for convenience, e.g.: RECord:DURation 3000 GTB sets the acquisition time to 3 seconds.

⚠ The availability of each SCPI command depends on the license you have selected for your Time Controller (see Section 3.1.6 – Software).

9.1 Common Commands

Common commands			
Command tree	Input	Output	Description
*IDN?		text	Machine identifier and version
STATe?		states	Returns the state of every functions/blocks
HELP?		SCPI commands	Returns all the available SCPI commands
OUTLoop			Small block that allows to link the source blocks to the input blocks internally
:LINK	address		Select the address from which to take the timestamps stream
:LINK?		address	Returns the linked address
:LINK:ADDResses?			Returns the valid addresses to which this function can be connected

9.2 Time Controller Commands

9.2.1 Device (DEVIce)

Common commands			
Command tree	Input	Output	Description
DEVIce			
:CALIbration:STATUS?		{SUCCESS |FAILURE |RUNNING }	Returns initial calibration status.
:CALIbration:EXECute			Recalibrates the Time Controller
:CONFIguration:LOAD	{COUNTercoincidence |HISTOgram |BLANK |INIT}		– Load predefined configurations: – COUNT: setup links as shown in Figure 27; – HISTO: restore links for histogram and timestamps acquisition; – BLANK: setup all links to NONE INIT: restore initial configuration
:LICEnse?		text	Returns the currently installed license
:NETWork:ADDRess:MANUal	IPv4 address (CIDR notation)		Set Time Controller manual (static) IP address for MANUal mode
:NETWork:ADDRess:MANUal?		IPv4 address (CIDR notation)	Return the Time Controller manual (static) IP address for MANUal mode
:NETWork:ADDRess:MODE	{AUTO |MANUal}		Set IP address allocation mode. – AUTO: from DHCP or APIPA – MANU: use manual IP address
:NETWork:ADDRess:MODE?		{AUTO |MANUal}	Get network IP address allocation mode
:NETWork:RESEt			Apply network interface changes
:LEDS	{ON|OFF}		Turns the LEDs interface ON or OFF
:LEDS?		{ON|OFF}	Returns the LEDs interface status
:RESolution	{HIRES |LOWRES}		Select the device resolution mode
:RESolution?		{HIRES|LOWRES}	Returns the device resolution mode
:RESEt			Reset the Time Controller
:SYNC	{INTernal |EXTernal}		Set the device clock location
:SYNC?		{INTernal |EXTernal}	
:STATe?			State of the block

9.2.2 Input (INPUt)

Use these commands to change parameters related to the inputs. You can replace # by the numbers 1 to 4 to refer to the input that is so labelled on the device's front panel.

Input block	INPU#		(# = 1...4)
Command tree	Input	Output	Description
INPUt#			Select input number
:ENABle	{ON|OFF}		Enable/disable input
:ENABle?		{ON|OFF}	
:COUNter?		number	Returns the number of counts over the integration time (CYCLE mode) or since last :RESEt (ACCUM mode)
:INTEgrationtime	time in ms		Set counter integration time (only in CYCLE mode)
:INTEgrationtime?		time in ms	Returns integration time
:MODE	{CYCLE|ACCUm}		Select the counter mode
:MODE?		{CYCLE|ACCUm}	Returns the counter mode
:RESEt			Reset counter to 0
:COUPling	{AC|DC}		Set AC or DC coupling
:COUPling?		{AC|DC}	
:EDGE	{RISIng|FALLing}		Set discriminator edge
:EDGE?		{RISIng|FALLing}	
:THREshold	value in V		Discriminator threshold
:THREshold?		value in V	
:HIREs:ERROr?		error code	Return last high resolution error code
:HIREs:ERROr:CLEAr			Acknowledge error
:SELEct	{UNSHaped|SHAPed|OUTPut|LOOP}		Select what feed the input block. For details, refer to the information below this table.
:SELEct?		{UNSHaped|SHAPed|OUTPut|LOOP}	Returns what feed the input port
:STATe?			State of the block

Additional information about the SELECt function:

- UNSHaped: The received signal from the physical input port is transmitted by the input block for further processing without any change
- SHAPed. The selected edge (rising or falling) of the received signal from the physical input port is considered as an event. This event is transmitted further by the input block by fixed width pulse (see sections 8.2.1.1 and 8.2.1.2).
  This mode is not available on the first generation of ID1000 (see section 8.2.1.2).

- OUTPut: The input block receives the data from the output block of the same label, e.g., INPUt3 receives the signal from the OUTPut3.
- LOOP: the input block receives the data from the block linked to the OUTLoop block.

Additional information about the HIREs:ERROr? returned error code:

Device	Error code	Description
All	0	No unacknowledged error.
ID900	1	Recalibration required (DEVI:SAMP:RECA).
ID900	2	Input count rate too high (above 25 MHz).
ID900	3-4	Time between two consecutive events is sometime too short.
ID900	5	Channel disabled (device reboot required).
ID1000	1001-1003	Signal rate too high or bad input threshold.

ID1000 only

- Some errors trigger automatic corrective actions leading to event loss on the impacted channel.
- If the problem persists despite proper signal rate and input threshold, try to recalibrate the device (a power-cycle might be required on some rare occurrences).

9.2.3 Start (STARt)

STARt block			
Command tree	Input	Output	Description
STARt			
:ENABle	{ON|OFF}		Enable/Disable Start
:ENABle?		{ON|OFF}	
:COUNter?		number	Returns the number of counts over the integration time (CYCLE mode) or since last :RESEt (ACCUM mode)
:INTEgrationtime	time in ms		Set counter integration time (only for CYCLE mode)
:INTEgrationtime?		time in ms	Returns integration time
:MODE	{ CYCLe|ACCUm}		Select the counter mode
:MODE?		{ CYCLe|ACCUm}	Returns the counter mode
:RESEt			Reset counter to 0
:COUPling	{AC|DC}		Set AC or DC coupling
:COUPling?		{AC|DC}	
:DELAy	value in ps		Set delay on start input
:DELAy?		Value in ps	
:EDGE	{RISIng|FALLing}		Set discriminator edge
:EDGE?		{RISIng|FALLing}	
STARt block			
Command tree	Input	Output	Description

:THREshold	value in V		Discriminator threshold
:THREshold?		Value in V	
:HIREs:ERROr?		error code	(ID1000 only) Return last high resolution error code (See section 9.2.2)
:HIREs:ERROr:CLEAr			Acknowledge error
:SELEct	{UNSHaped| SHAPed| LOOP}		Select what feed the START block.
:SELEct?		{UNSHaped| SHAPed|LOOP}	Returns what feed the input port
:STATe?			State of the block

Additional information about the SELECt function:

- UNSHaped: The received signal is transmitted by the input block for further processing without any change
- SHAPed. The selected edge of the received signal is considered as the event. This event is transmitted further by the START block by fixed width pulse (see sections 8.2.1.1 and 8.2.1.2).
  This mode is not available on the first generation of ID1000 (see section 8.2.1.1).
- LOOP: the input block receives the data from the block linked to the OUTLoop block.

9.2.4 Delay (DELAy)

DELAy block		DELA#	(# = 1...8)
Command tree	Input	Output	Description
DELAy#			
:LINK	address		Selects the block from which to take the timestamp stream
:LINK?		address	Returns the block from which the timestamp stream is taken
:LINK:ADDResses?		list of addresses	Returns the valid addresses to which this block can be connected.
:VALUe	number		Set delay in ps
:VALUe?		number	Returns delay in ps

9.2.5 Output (OUTPut)

Output block		OUTP#	(# = 1...4)
Command tree	Input	Output	Description
OUTPut#			Selects output number #
:ENABle	{ON|OFF}		Enables or disables the output
:ENABle?		{ON|OFF}	
:MODE	{NIM|TTL}		Sets output level to NIM or TTL
:MODE?		{NIM|TTL}	
:LINK	address		Selects the block from which to take the timestamp stream
:LINK?		address	
:LINK:ADDResses?		list of addresses	Returns the valid addresses to which this block can be connected.
:PULSE	{ON|OFF}		Enables the pulse mode of the output
:PULSE?		{ON|OFF}	
:PULSE:WIDTH	Pulse width in ps		Pulse width in ps
:PULSE:WIDTH?		Pulse width in ps	
:DELAY	delay in ps		Set delay in ps
:DELAY?		delay in ps	
:STATe?			State of the block

Additional information about the Pulse function:

- The output generates a pulse of the chosen width every time an event (rising edge) arrives at the in-port of the output block

9.2.6 Timestamp generator (GENerator)

Creates pulse sequences programmatically, triggered by the internal device clock or external detection events.

Timestamp generator block	GEN#		(# = 1...8)
Command tree	Input	Output	Description
GENerator#			
:ENABle	{ON|OFF}		Enables/disables the generator
:ENABle?		{ON|OFF}	
:PWIDth	pulse width in ps		pulse width in ps
:PWIDth?		pulse width in ps	
:PPERiod	period in ps		Separation between pulses in ps
:PPERiod?		period in ps	
:PNUMber	Number		Number of pulses, from 1 to 65535 or INF (or 0) for an infinite sequence.
:PNUMber?		number	
:PLAY			Force generator into “Playing” stage.
:STOP			Force generator out of “Playing” stage.
:TRIGger			
:ARM:MODE	{AUTO|MANUal}		Set the trigger arming mode of the generator.
:ARM:MODE?		{AUTO|MANUal}	
:ARM			Manually arm the trigger.
:DARM			Manually disarm the trigger.
:DELAY	delay in ps		Delay the output with respect to the trigger.
:DELAY?		delay in ps	
:LINK	Address		
:LINK?		address	
:LINK:ADDResses?	Address		Valid link addresses
:STAGe?		{IDLE|WAITing|ARMed|PLAYing}	Current working stage of the generator.
:STATe?			State of the block

GENerator examples:

- SCPI command to configure Generator 5 to produce a 1MHz clock signal:

  GEN5:ENAB ON;PNUM INF;PPER 1000000;PWID 500000;PLAY

- SCPI command to configure Generator 1 to produce 15 pulses, each 4 ns wide and spaced 10 ns apart, when triggered by a signal from DELA1 (INPU1 by default):

  GEN1:ENAB ON;PNUM 15;PPER 10000;PWID 4000;TRIG:LINK DELA1;ARM:MODE AUTO

- SCPI command to combine the above two examples, producing a 15-pulse sequence once every microsecond:

  GEN1:TRIG:LINK GEN5

9.2.7 Record generator (RECord)

Control the acquisition time of HISTogram and RAW blocks. Apart from this specialized task, the RECord block work as any other GENerator block, and shares the exact same set of commands.

To simplify its usage, the following additional commands are available.

Record generator block		REC	
Command tree	Input	Output	Description
RECord#			
:DURation	time in ps		Record time in ps
:DURation?		time in ps	
:NUMber	number		Number of consecutive acquisitions, from 1 to 65535 or INF for an infinite number of acquisitions.
:NUMber?		number	

9.2.8 Timestamp combiner (TSCOmbiner)

Timestamp combiner block	TSCO#		(# = 1...24)
Command tree	Input	Output	Description
TSCOmbiner#			
:COUNter?		number	Returns the number of counts over the integration time (CYCLE mode) or since last :RESEt (ACCUM mode)
:INTEgrationtime	time in ms		Set counter integration time (only for CYCLE mode)
:INTEgrationtime?		time in ms	Returns integration time
:MODE	{CYCLE|ACCUM}		Select the counter mode
:MODE?		{CYCLE|ACCUM}	Returns the counter mode
:RESEt			Reset counter to 0
:OPIN	{ONLYFIR |ONLYSEC |AND |OR |MUTE}		Set the operation performed inside the windows. For details, refer to information below the table.
:OPIN?		{ONLYFIR |ONLYSEC |AND |OR |MUTE}	
:OPOUt	{ONLYFIR |ONLYSEC |AND |OR |MUTE}		Set the operation performed outside the windows. For details, refer to information below the table.
:OPOUt?		{ONLYFIR |ONLYSEC |AND |OR |MUTE}	
:FIRst			
:LINK	address		Block to connect to this port
:LINK?		address	
LINK:ADDResses?		addresses	Valid addresses
:SECond			
:LINK	address		Block to connect to this port
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses

Timestamp combiner block	TSCO#		(# = 1...24)
Command tree	Input	Output	Description
:WINDow			
:ENABle	{ON|OFF}		
:ENABle?		{ON|OFF}	
:BEGIn			
:LINK	address		Block to connect to this port
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses
:EDGE	{RISING | FALLING}		
:EDGE?		{RISING | FALLING}	
:DELAY	delay in ps		Add a delay to the windows begin. Max value: 4 ms
:DELAY?		delay in ps	
:END			
:LINK	address		Block to connect to this port
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses
:EDGE	{RISING | FALLING}		
:EDGE?		{RISING | FALLING}	
:DELAY	delay in ps		Add a delay to the windows end. Max value: 4 ms
:DELAY?		delay in ps	
:STATe?			State of the block

Additional information about the Operations OPIN/OPOUt:

- ONLYFIR: Transfer only timestamps from the FIRst LINK
- ONLYSEC: Transfer ONLY the timestamps from the SECond LINK
- AND: Perform an “AND” gate between the FIRst and SECond LINK.
- OR: Perform an “OR” gate between the FIRst and SECond LINK.
- MUTE: No timestamps transferred.

9.2.9 HISTogram

Use this block to generate histograms on board.

HISTOgram block		HIST#	(# = 1...4)
Command tree	Input	Output	Description
HISTogram#			
:REF			
:FILTer	{RISIng|FALLing|ALL}		Type of edge to consider as reference event
:FILTer?		{RISIng|FALLing|ALL}	
:LINK	address		Select source block from which timestamps are from
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses
:STOP			
:FILTer	{RISIng|FALLing|ALL}		Type of edge to consider as stop event.
:FILTer?		{RISIng|FALLing|ALL }	
:LINK	address		Select the source block from which timestamps are from
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses
:ENABle			
:LINK	address		Select the source block from which the timestamps are
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses
:MINimum	time		Minimum histogram value in ps
:MINimum?		time	
:BWIDth	time		Histogram time bin width in ps
:BWIDth?		time	
:BCOUnt	number		number of bins; <16384.
:BCOUnt?		number	
:DATA?			Return histogram
:FLUSh			Clear histogram
:STATe?			State of the block

Additional information: when both REF:LINK and STOP:LINK share the same source; the histogram enters in autocorrelation mode, which measures the time difference between two consecutive events.

9.2.10 Raw data (RAW)

Use this block to transfer timestamps value to a computer.

RAW block		RAW#	(# = 1...4)
Command tree	Input	Output	Description
RAW#			
:REF			
:LINK	address		Select the source block from which the timestamps are
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses
:STOP			
:LINK	address		Select the source block from which the timestamps are
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses
:ENABle			
:LINK	address		Select the block to which the timestamps are from
:LINK?		address	
:LINK:ADDResses?		addresses	Valid addresses
:NUMerator	{1|100}		Multiplier of the time-base unit TB before export
:NUMerator?		{1|100}	
:DENOminator	{1}		Divider of the time-base unit TB before export
:DENOminator?		{1}	
:STATe?			State of the block

10 Appendix: DLT Command Reference

The DataLinkTarget (DLT) Service is responsible for the Time Controller's timestamps reception on the host computer. It is controlled by commands sent though ZMQ to the host computer on port 6060.

10.1 Command answer format

All DLT commands return an text answer in JSON (JavaScript Object Notation) which is either a JSON object (key/value pair) or JSON list.

If for any reason, a command fails, it answers with a JSON object with an "error" key, itself containing an object which describes the error (example below).

```
{"error":{"description":"unrecognised option '--xyz'"}}
```

10.2 Commands

10.2.1 start-save

Description	Open an acquisition which saves timestamps in a file on disk.	
Command	start-save	
Arguments	--id <ID>	(Optional) Associates <ID> to the newly opened acquisition. If this argument is omitted, a unique ID is automatically generated.
	--address <ADDR>	IP Address <ADDR> of the target Time Controller.
	--channel <CHAN>	Channel <CHAN> to acquire.
	--filename <PATH>	Full or relative path to the timestamps file. If the path is relative, the file is stored in the default folder defined when the DLT was executed.
	--format <FMT>	Timestamps file format choice <FMT>: • bin: binary format (recommended format: fast to save and process) • txt: ASCII format (not recommended: slow to save and process but human readable)
	--with-ref-index	Write reference indexes in the timestamps file.
Answer	Returns the ID associated to the newly opened acquisition. Answer example: `{"id":"10.98.99.7:5556"}`	

10.2.2 start-stream

Description	Open an acquisition which streams timestamps over ZMQ (exclusive pair pattern).
Command	start-stream

Arguments	--id <ID>	(Optional) Associates <ID> to the newly opened acquisition. If this argument is omitted, a unique ID is automatically generated.
	--address <ADDR>	IP Address <ADDR> of the target Time Controller.
	--channel <CHAN>	Channel <CHAN> to acquire.
	--stream-port <PORT>	ZMQ port on which the client can listen to the stream.
	--with-ref-index	Write reference indexes in the timestamps file.
Answer	Returns the ID associated to the newly opened acquisition. Answer example: `{"id":"10.98.99.7:5556"}`	

10.2.3 stop

Description	Close the designated opened acquisition.	
Command	stop	
Arguments	--id <ID>	ID associated to the acquisition to stop.
Answer	Returns the status (see status command for more detail) of the closed acquisition. Answer example: `{ "status": { "acquisitions_count": 1, "errors": [], "inactivity": 1.054841, "timestamps_count": 0 } }`	

10.2.4 list

Description	List currently opened acquisitions.
Command	list
Arguments	-
Answer	List of opened acquisitions. Answer example: `[ "10.98.99.7:5556", "10.98.99.7:5557", "10.98.99.7:5558", "10.98.99.7:5559" ]`

10.2.5 status

Description	Monitor the status of an opened acquisition.	
Command	status	
Arguments	--id <ID>	ID associated to the acquisition to monitor.

Answer	Return the acquisition status (example below), where:
	- `acquisition_count`: the number of acquired records
	- `errors`: list of errors which occurred so far
	- `inactivity`: seconds since the last message was received from the Time Controller.
	- `timestamps_count`: total number of received timestamps
	
	Answer example:
	`{`
	`"acquisitions_count": 0,`
	`"errors": [],`
	`"inactivity": 1.124206,`
	`"timestamps_count": 0`
	`}`

The status reported values allows for a basic monitoring of an ongoing acquisition.

- `acquisition_count`: should be equal to number of desired records, defined by the SCPI command `RECord:NUMber?` and usually equals 0 during the acquisition and 1 upon its completion.
- `errors`: should be an empty list.
- `inactivity`: should not exceed a few seconds after the end of the acquisition. This would mean that the Time Controller is not sending any data to the DLT.
- `timestamps_count`: total number of received timestamps.