sensL
sense light

High Resolution Time-to-Digital Converter Module

Document Overview

This document provides the user with a comprehensive description of the hardware and software of the HRM-TDC module, including system description, the various timing modes, software GUI and DLL drivers. The document is split up into the following sections:

GETTING STARTED

This section provides instructions for unpacking the HRM-TDC and a brief overview.

SYSTEM DESCRIPTION

This section gives a description of the system hardware, the various ports and communication channels, the internal processor, and the specific timing features.

SENSL INTEGRATED ENVIRONMENT (SIE)

The SIE is a user interface for setting up and controlling the HRM-TDC module. While the interface provides an extensive range of operating modes and measurement processes, including graphical presentation, it does not fully cover all features available in the HRM-TDC module. This section of the User Manual includes instructions for the installation of the necessary software, and detailed description of each part of the SIE and how to set up and use it.

APPENDIX

The HRM-TDC DLL provides a set of functions that will allow full control of the HRM-TDC for all features. For complex experiments that require control beyond the scope of the SIE, it is expected that the user will write their own real-time application utilizing the various functions in this DLL. The Appendix of the User Manual covers Registers, low level DLL functions, high level DLL functions, DLL error reporting and examples, as well as help and examples for resolving time-tag values,an explanation of the correlation function used and the Labview drivers provided.

Contents

Glossary

Here are words and phrases used in this user manual in relation to the HRM-TDC module.

SIE - SensL Integrated Environment - the GUI that runs on the SensL DLL and provides an example program allowing the user to make measurements with the HRM-TDC.

LSB - Least Significant Bit: The right most bit in a binary integer, and in the case of the HRM-TDC it determines the minimum timing resolution possible.

Histogram - The use of consecutive memory locations to store counts that represent points on a graph. Each memory location represents a time range that can be specified via software, down to the LSB value of the HRM-TDC (27ps).

FIFO - First In, First Out: in the HRM-TDC, timing data can be stored in memory before being downloaded to the PC. FIFO is analogous to putting the data into a queue in memory, whereby the first loaded in, will also be the first downloaded to the PC.

TCSPC - Time Correlated Single Photon Counting: A technique used to study properties of molecules by exciting with a laser source and measuring the subsequent relaxation time through the acquisition of lifetime curves.

Time bin - The time interval covered by one memory location in one of the HRM-TDC's Histogram modes.

Time Tag - The timing value recorded between a START of a STOP signal, in one of the HRM-TDC's FIFO modes.

Curve - The data resulting from one of the HRM-TDCs histogramming modes.

Micro time - The timing value between a START signal and any given STOP signal in FIFO single-stop (TCSPC) mode. In the FIFO multi-stop (time-tagging) mode, it refers to the value of the high-resolution TDC when the event occured.

Macro time - The time elapsed since the experiment began in FIFO single-stop (TCSPC) mode. In FIFO multi-stop (time-tagging) mode, it refers to the the coarse timer that, used in conjunction with the micro-time, allows the user to determine the absolute time of the event.

Getting Started

CONTACT & SUPPORT

For all enquiries, please email: support@sensl.com

Supporting documentation can be found on the SensL website at www.sensl.com/documentation/

Downloadable copies of the SensL HRM-TDC software and release note can be found at www.sensl.com/support/sw/

UNPACKING THE SYSTEM AND PREPARING FOR USE

Unpack the contents and identify each of the components.

- HRM-TDC Module
- Power Supply, with country specific connector
- USB cable

SAFETY CONSIDERATIONS

1. Only use the power supply supplied with the HRM-TDC module.
2. The power supply should be disconnected from the mains supply when the module is not in use.
3. The module is not intended for outdoor use
4. The power supply should not be opened nor should the module covers be removed at any time as there are no user adjustable components or settings, except via the SensL Integrated Environment Software.
5. Liquids should not be spilled on or into the module.

SYSTEM INSTALLATION PROCEDURES

For software driver and SensL Integrated Environment installation instructions see the SIE User Guide on page 18 of this document.

Please follow the instructions carefully and ensure you have installed the QuickUSB drivers as instructed.

SYSTEM CHARACTERISTICS AND SPECIFICATIONS

Dimensions

164mm (L) x 96mm (W) x 34 mm (H)

Weight

680g

Power

+5V @ 0.65 A

Temperature

Operating: 0°C to +50°C
Storage: -20°C to +70°C

Specifications

Number of channels per module	4
Time channels per curve	1 to 4,194,304
Number of curves in memory	1 to 4,194,304
Input voltage range	LVTTL (5V TTL tolerant)
START/STOP channels input impedance	51kΩ
Minimum input pulse width	6ns
Minimum Time/Channel	27ps
Histogram/channel depth	65,535 or 4,294,967,295 bits (16 or 32 bits)
Dead time	190ns
Saturated count rate	4.5MHz
Usable count rate	9MHz *
Burst rate timing	Up to 100MHz (Mode dependent)
Macro Timing resolution	Down to 5ns
Memory size	8Mbytes
Memory format	Dual ported linear or dual ported FIFO (mode dependent)
Readout during operation	Fully dual-ported memory (no stop start operation required)
Multi detector operation	Up to 4
Multi module operation	Number depends on USB capability of PC
I/O control	16 fully programmable I/O ports
Software	SensL Integrated Environment (SIE) and DLL drivers
PC Interface	High speed USB 2.0

** Useful count rate is maximum count rate without loss of greater than 50%*

SIGNAL INPUTS AND OUTPUTS

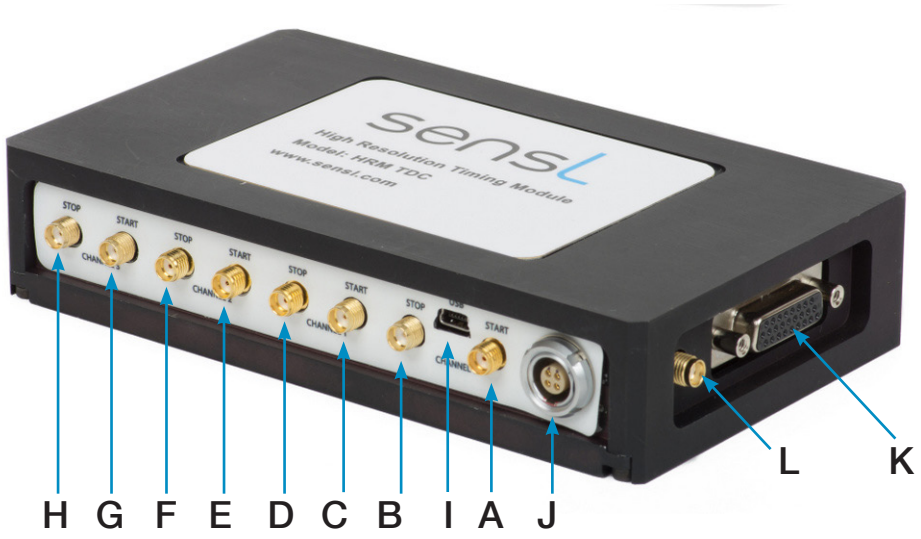
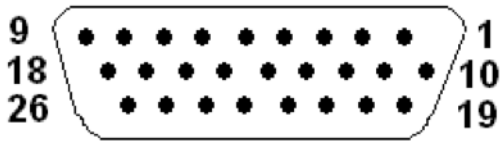


Figure 1 HRM-TDC ports and connectors labelled

A Channel 0 Start Input (SMA LVTTL*)
B Channel 0 Stop Input (SMA LVTTL*)
C Channel 1 Start Input (SMA LVTTL*)
D Channel 1 Stop Input (SMA LVTTL*)
E Channel 2 Start Input (SMA LVTTL*)
F Channel 2 Stop Input (SMA LVTTL*)
G Channel 3 Start Input (SMA LVTTL*)
H Channel 3 Stop Input (SMA LVTTL*)
I USB connector
J LEMO power supply connector (for SensL PSU use only)
K 26-way I/O port connector
L Programmable Clock output (SMA LVTTL 50Ω)

** 5V TTL tolerant*

I/O PORT CONNECTOR PIN ALLOCATION



Pins 1 to 16:	I/O ports 0 to 15 respectively
Pin 17:	Test clock signal ENABLE (LO to disable test clocks)
Pin 18 to 22:	Test clock signals (outputs)
Pin 23, 24:	+5v
Pin 25, 26:	Ground

HRM-TDC System Description

BLOCK DIAGRAM

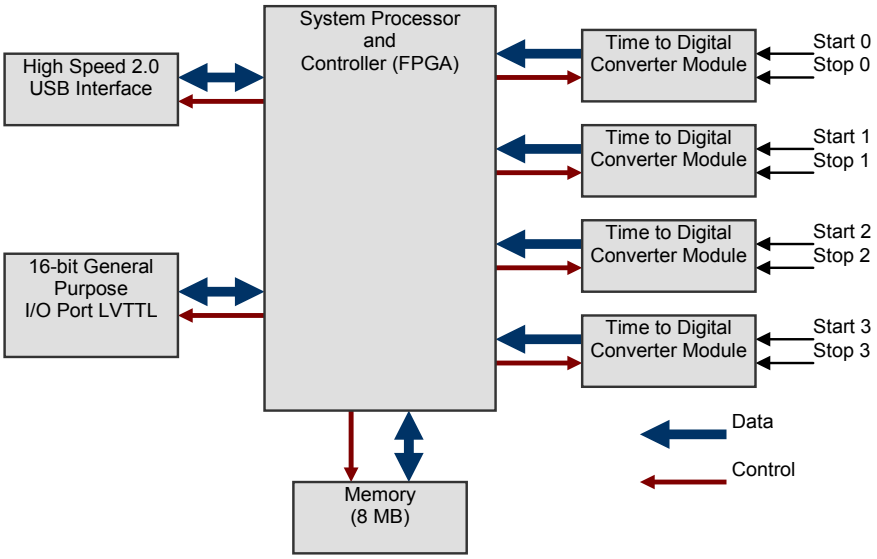


Figure 2 An overview of the HRM-TDC operation

The HRM-TDC system consists of 4 'time-to-digital' modules (each having a START and a STOP input), 16 I/O ports, a high speed USB interface, memory storage and an FPGA based processor, as depicted in Fig. 2. The purpose of each element is as follows:

Memory

The memory module is an HRM-TDC format plug-in mezzanine board providing 8 Mbytes of memory.

Time-to-Digital Converter Module

This module is the front end of the system and is responsible for resolving the timing between the START and STOP inputs of each of up to four channels. Each channel is controlled by the FPGA and can be programmed to start and stop on either LO-HI or HI-LO transitions.

High Speed USB 2.0 Interface

The USB interface is used to command/configure the HRM-TDC as well as download, in real-time, timing data to the host computer. This USB interface implements high speed USB 2.0 protocol allowing real time continuous logging of timing data up to rates of 4.5MHz without data loss.

16-Bit General Purpose I/O Port

This general purpose I/O port is used to allow multi-dimensional curve readings. The position of curve data, within the system memory, can be defined by these ports. These ports can be set directly by outside control lines (inputs) or by software to drive outside equipment (outputs).

System Processor and Controller

The 'System Processor/Controller' is responsible for implementing all the functionality of the HRM-TDC module. This module decodes commands from the USB and executes the timing function accordingly. All results are saved in memory as either ***time-bins*** for curve measurements or ***time-tags*** for continuous recording. In this latter mode the memory is configured as a large FIFO to allow continuous downloading of time-tag data up to rates of 4.5MHz.

SYSTEM PROCESSOR AND CONTROLLER DETAILED DESCRIPTION

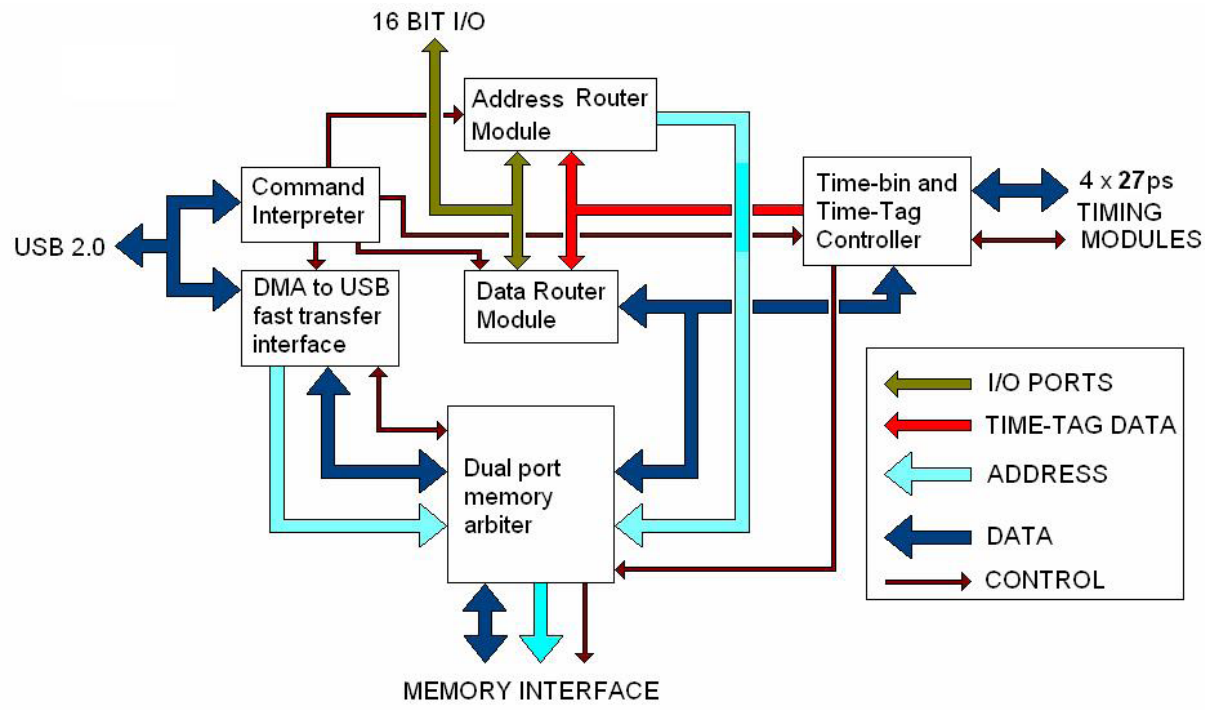


Figure 3 Overview of the system processor and controller

Command Interpreter

This module is responsible for receiving a set of commands from the host computer and controlling the system accordingly. HRM-TDC is a fully programmable system with a wide range of parameters that can be user defined. The Command Interpreter is responsible for setting these parameters and starting the execution of a particular task.

DMA to USB Fast Transfer Interface

The system memory is dual ported between the USB and the Time-Bin/Time-Tag controller. This module controls the reading of data from memory to the USB interface by means of high speed DMA block transfers. The Command Interpreter initializes this module with a start address and block data count. When commanded to start, this module interfaces with the Dual Port Memory Arbiter to read the pre-programmed data block. The rate of this process is such that data can be transferred from the memory to the USB port as fast as required. This allows the USB 2.0 high speed interface to operate at full speed without loss of data.

Time-Bin and Time-Tag Controller

This module is responsible for carrying out the particular Time-Tag or Time-Bin process as defined by the Command Interpreter. This module communicates with the Timing Modules and saves the results of the measurements in the dual ported memory. The format of these results is determined by the mode of operation. In time-bin mode, this module will use the time information from the Timing Modules to determine the particular bin to be incremented. In time-tag mode this module will treat the memory as a large FIFO, saving time-tag data in consecutive locations. The format of the time-tag data is determined by the Data Router Module.

Data Router Module

The Data Router Module is a complex programmable multiplexer that allows any of a wide range of inputs to be routed to any of the 32 memory data bits. In time-bin mode this module is bypassed to allow the Time-Bin and Time-Tag Controller to directly access the memory for the purpose of incrementing time-bins. In Time-Tag mode this module determines the format of the time-tag data. The Command Interpreter presets the routing of this module to define which bits of the time-tag are Time-Tag data (both Micro and Macro) from the Time-Bin and Time-Tag Controller and I/O data from external equipments.

Address Router Module

The Address Router Module is a complex programmable multiplexer that allows any of a wide range of inputs, plus an internal address counter, to be routed to any of the memory address lines. In time-tag mode this module will normally be programmed to present the internal address counter bits as the memory address. The internal address counter automatically increments after each memory write, creating a FIFO type interface. In time-bin mode the Command Interpreter presets the routing of this module to a mix of the address counter, time-tag data and I/O data. Routing the time-tag data to the address will create a range of consecutive bins separated by the time resolution of the LSB. The address counter bits can be used to define the base address of a particular curve whilst the I/O data can be used by external equipments to move the curve for multi-dimensional measurements.

Dual Port Memory Arbiter

This module controls the data transfers to/from system memory to the USB and Time-Bin/Time-Tag Controller. Each port presents an address, direction (R/W) and request signal. This module detects the particular request, carries out the memory access and directs the data to/from the requesting port at the requested address.

HRM-TDC TYPICAL APPLICATION

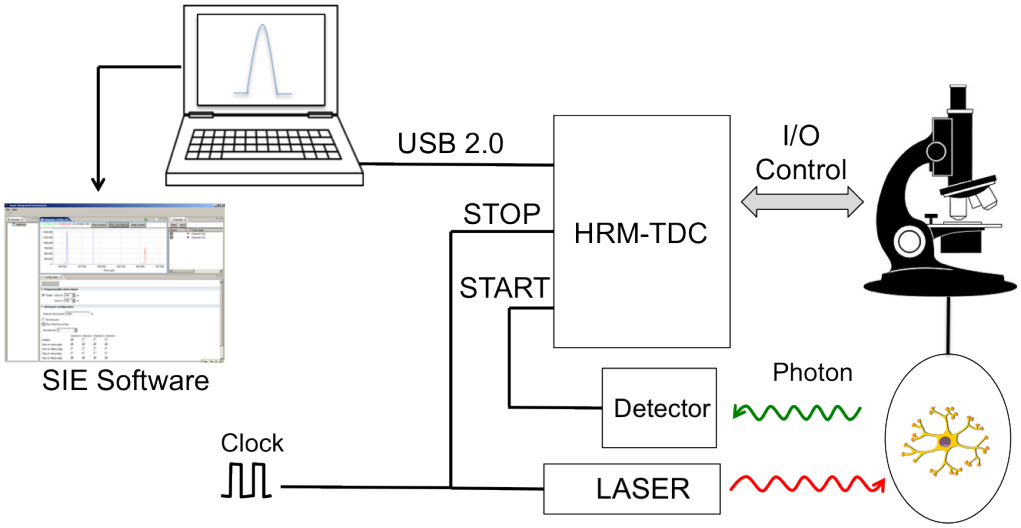


Figure 4 Example application using the HRM-TDC

Note: Figure 4 shows a typical application setup utilizing a wide range of the HRM-TDC features. In this example the experiment is a TCSPC application where a LASER is stimulated by a clock and the time before a photon is detected is measured. The LASER is continually pulsed at a fixed frequency (typically 50MHz). The LASER output will affect a setup resulting in a photon arriving at the APD Detector such as the SensL PCDMiniSL. It is assumed that the rate of photons arriving at the APD is far less than the rate of the LASER pulses. As a photon is not guaranteed for each cycle of the LASER, the system will use the photon event as the start of the TCSPC process and a delayed version of the LASER pulse as the stop signal. This technique avoids countless dead cycles and simplifies the associated electronics required for recording the events.

The HRM-TDC module measures and records the time delay between clock and photon from the experiment and uploads the results, in real time, to the host computer via the USB interface. In some cases the experiment will involve multiple TCSPC curve measurements as the experiment changes the settings of external equipment. The programmable I/O of the HRM-TDC module is used to cater for such applications. The external equipment, such as a microscope, can indicate its X,Y movement to the HRM-TDC module allowing multiple curves to be measured. Alternatively, the HRM-TDC module can be programmed as outputs to control the external equipment and cause the actual X,Y positioning of the equipment.

HRM-TDC SPECIFIC FEATURE OVERVIEW

The flexibility of the HRM-TDC allows it to be used in a variety of modes. The following are examples of how the SIE software utilizes the START and STOP signals in different ways to cater for different applications.

HISTOGRAM

Histogram modes use consecutive memory locations to store counts that represent points on a graph. These memory locations or ***time bins*** are incremented based on the value of a time measurement. Each memory location represents a time range equal to the resolution of the timer. Within the HISTOGRAM category there are two distinct modes of operation, single-stop and multi-stop.

Single-stop histogram

Following a START event, **the first** stop event is measured and the corresponding time bin is incremented. This is repeated to build up a histogram (curve) in memory showing the distribution of 1st events following a start input. This mode is also referred to as "TCSPC" mode due to its application in Time Correlated Single Photon Counting.

Multi-stop histogram

Following a START event, **all stop** events are measured and their corresponding time bins incremented. The next START input will reset the timer and the following events processed again. This is repeated to build up a histogram in memory showing the distribution of STOP events following a START input. This mode is also referred to as "Multiscaler/Counter" mode.

FIFO

FIFO modes continually record the timing of events and save the results in consecutive locations in memory. When the last location in memory is filled, if not commanded to stop, the module continues to record data starting at the beginning of memory again. The host PC, via the USB interface, keeps up in time with the module, reading the data from memory to a file in the host computer. Hence the memory can be regarded as a very large FIFO. Providing the host PC can keep up with the module, timing data can be recorded indefinitely. Within the FIFO category there are two distinct modes of operation, single-stop and multi-stop.

Single-stop FIFO

In this mode the module carries out the single-stop histogram process as described previously. However, along with the single-stop measurement, the information stored in the FIFO also has a ***MACRO time*** that defines what time during the experiment the timing measurement was made. This mode is also referred to as "TCSPC with Macro time".

Multi-stop FIFO

This mode is also referred to as "FIFO time tagging" and offers 2 options:

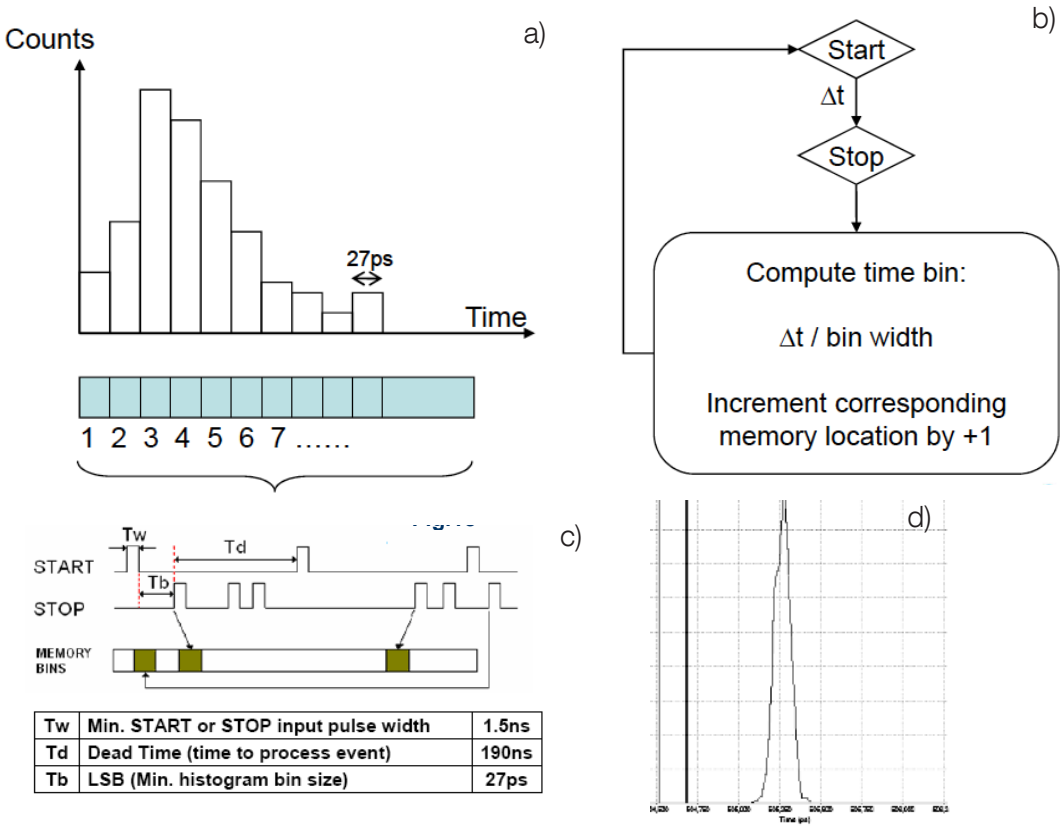
Free Running:

Using this option the process is started with a single start pulse. The module will then fill the memory with time tags defining the time of each stop event with relation to the initial single start pulse. Any further Start inputs will be ignored.

Resync:

This option uses a 250KHz clock output from the module as the Start input. The clock continuously re-synchronizes the module to eliminate long term drift between channels. This is the preferred method when it is required to compare the data from more than one channel.

HISTOGRAM – SINGLE-STOP ("TCSPC" MODE)



Tw	Min. START or STOP input pulse width	1.5ns
Td	Dead Time (time to process event)	190ns
Tb	LSB (Min. histogram bin size)	27ps

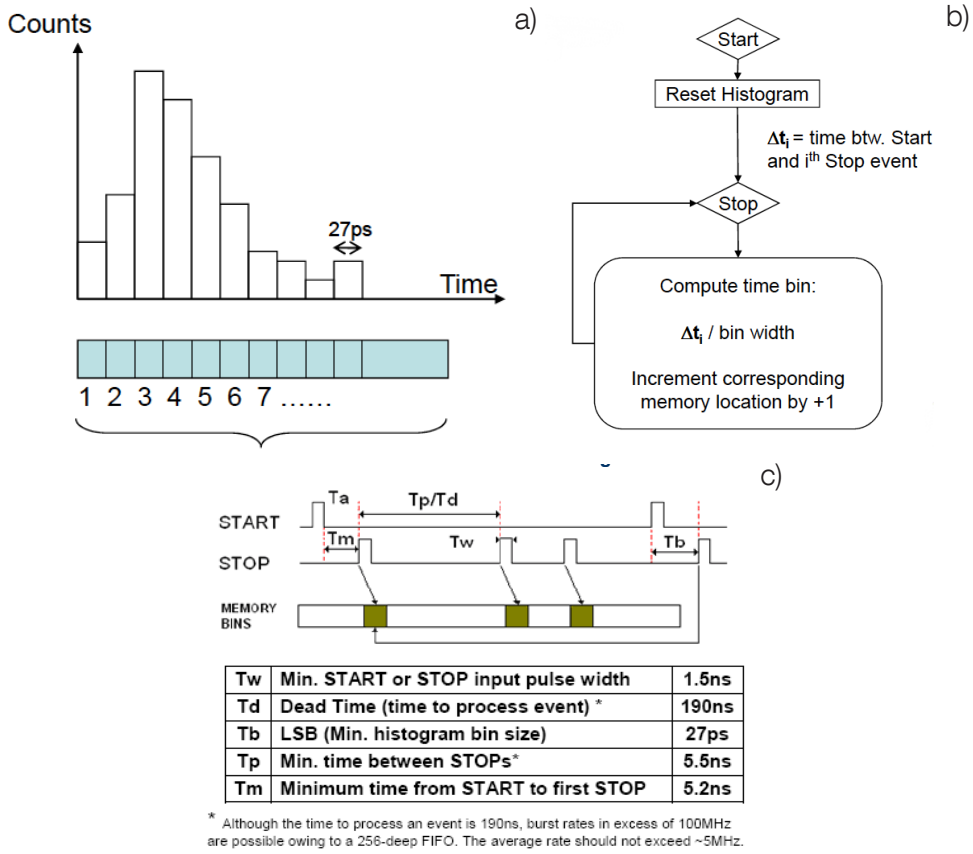
Figure 5

Histogram modes use consecutive memory locations to store counts that represent successive timing values (Fig.5a). These memory locations or "time bins" are incremented based on the result of a time measurement between a START and the first STOP received. In this single-stop mode, this is repeated to build up a histogram in memory showing the distribution of first events (STOPs) following a START input. This process is illustrated in Fig.5b and Fig.5c, and an example GUI data plot is shown in Fig.5d. Data is saved to the PC in .CSV format. This mode is also referred to as '**TCSPC**' in the SIE, due to its application in Time Correlated Single Photon Counting.

Note: In this mode the START of each channel will be the event and the STOP will be a delayed version of the LASER clock. On receipt of an event the timing value will be read and then the timing module will immediately be reset. The reset will clear the channel ready for the next event. Each time-stamp from the timing module will be used as an address to increment a memory location (time-bin). The resolution of the bins and the position of the curve in memory will be defined by the highly flexible Address Routing Module. The timing value, address counter and I/O bits can all be routed to the memory address lines. This flexibility allows many options, from a simple single curve to multiple curves defined by the address counter and external control from the I/O port.

Min Time Bin Size:	27ps
Max Time Bin Size:	143µs
Max No. Time Bins:	4,194,304
Time Bin Depth:	65,536 or 4,294,967,296
Max Count Rate:	4.5Mcps
Max Image Size:	2048 x 4096

HISTOGRAM – MULTI-STOP ("MULTISCALER/COUNTER")



Tw	Min. START or STOP input pulse width	1.5ns
Td	Dead Time (time to process event) *	190ns
Tb	LSB (Min. histogram bin size)	27ps
Tp	Min. time between STOPs*	5.5ns
Tm	Minimum time from START to first STOP	5.2ns

* Although the time to process an event is 190ns, burst rates in excess of 100MHz are possible owing to a 256-deep FIFO. The average rate should not exceed ~5MHz.

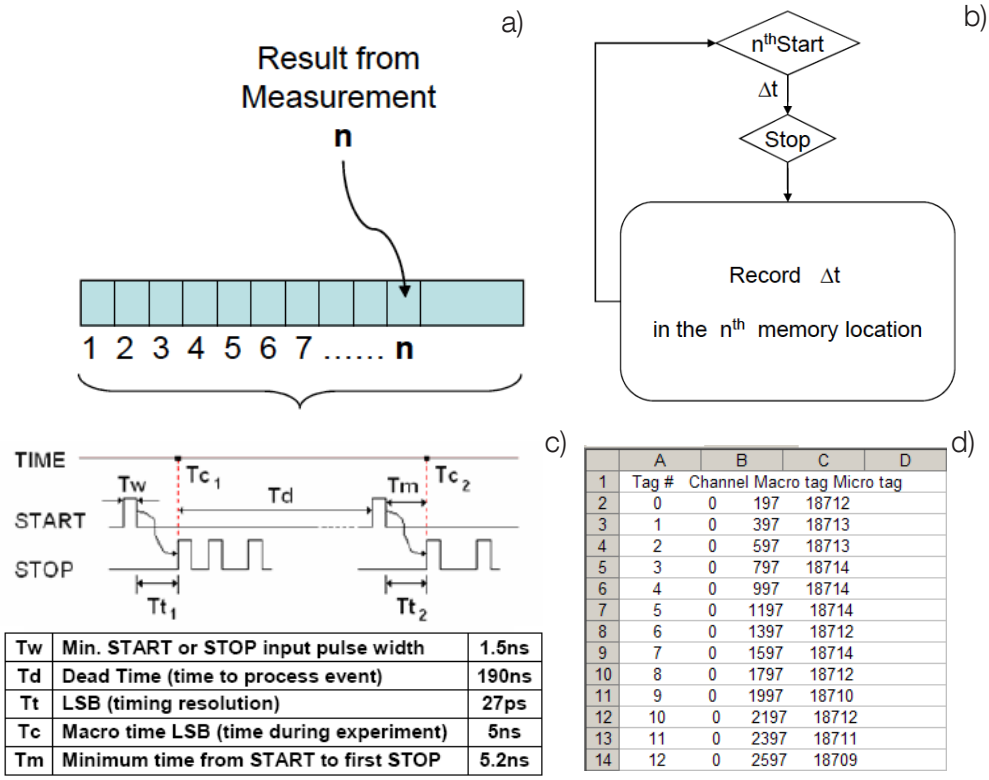
Figure 6

In this mode, all STOP events following a given START event are measured and their corresponding time bins in the histogram incremented (Fig.6a). The following START input will reset the timer and the following STOP events will be again recorded until another START is received. The process is illustrated in Fig.6b and Fig.6c. This is repeated to build up a histogram in memory. Data is saved in .CSV format. The GUI will display a plot similar to that in Fig.5d. This mode is also referred to as "**Multiscaler/Counter"** in the SIE.

Note: In this mode the START signal is a low frequency clock (less than 7 MHz). The STOP signals will be the events. Unlike the single-stop mode, the 27ps timing module is not reset after the first event. Due to the long clock period it will be possible for the same channel to receive a number of events per clock cycle. Hence, in this mode the time-bins will fill up to plot the occurrence of events over the period of the clock cycle. Each new START signal will reset the 27ps timing module. This allows the system to build up a plot of all the events within the START pulse cycle. Once again the flexibility of the Address Routing Register provides a wide range of options from single to multiple curves.

Min Time Bin Size:	27ps
Max Time Bin Size:	143μs
Max No. Time Bins:	4,194,304
Time Bin Depth:	65,536 or 4,294,967,296
Max Count Rate:	4.5Mcps
Max Image Size:	2048 x 4096

FIFO – SINGLE-STOP ("TCSPC - WITH MACRO-TIME")



Tw	Min. START or STOP input pulse width	1.5ns
Td	Dead Time (time to process event)	190ns
Tt	LSB (timing resolution)	27ps
Tc	Macro time LSB (time during experiment)	5ns
Tm	Minimum time from START to first STOP	5.2ns

	A	B	C	D
1	Tag #	Channel	Macro tag	Micro tag
2	0	0	197	18712
3	1	0	397	18713
4	2	0	597	18713
5	3	0	797	18714
6	4	0	997	18714
7	5	0	1197	18714
8	6	0	1397	18712
9	7	0	1597	18714
10	8	0	1797	18712
11	9	0	1997	18710
12	10	0	2197	18712
13	11	0	2397	18711
14	12	0	2597	18709

Figure 7

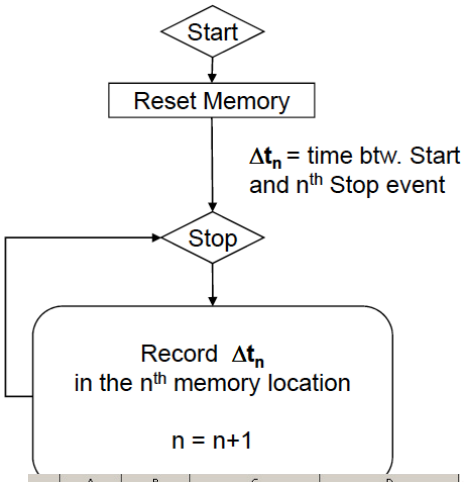
FIFO modes continually record the timing of events and save the results in consecutive locations in memory as shown in Fig.7a. When the last location in memory is filled, if not commanded to STOP, the module continues to record data starting at the beginning of memory again. The host PC, via the USB interface, keeps up in time with the module, reading the data from memory to a file in the host computer. Hence the memory can be regarded as a very large FIFO. Providing the host PC can keep up with the module, timing data can be recorded indefinitely.

In this mode the module carries out the Single-STOP process as described previously and illustrated in Fig.7b and Fig.7c. However, along with the timing of the Single-STOP event, a MACRO time (the time during the experiment that this measurement is made) is also recorded. Both times are recorded in the FIFO. An example of the data recorded is shown in Fig.5d. Data is saved in .CSV format. This mode is also referred to as '**TCSPC (with Macro Time)**' in the SIE, due to its application in Time Correlated Single Photon Counting.

Note: In this mode the START of each channel will be the event and the STOP will be a delayed version of the LASER clock. On receipt of an event the timing value will be read and the MICRO time will be immediately reset. The reset will clear the channel ready for the next event. All subsequent STOP pulses will be ignored until a new START pulse arrives. Each time-stamp will be a 32-bit word giving the time since the last START (MICRO-time Tt_1 or Tt_2 in Fig.7c) and the value of a free running clock defining the time within the experiment (MACRO-time Tc). Due to the highly flexible Data Routing Module the resolution and number of bits for the micro time, macro time and channel ID bits is selectable using the USB selection registers. When this process begins, 32-bit timing values will be inserted into the shared memory. The memory will be configured as a large FIFO interfacing to the USB interface. Suitable handshake signals are implemented allowing continuous transfer of time-tags from the FIFO to the PC via the USB port. With counts of up to 4.5MHz this process can run indefinitely without loss of data.

FIFO – MULTI-STOP ("FIFO - TIME TAGGING")

a)



b)

	A	B	C	D
1	Tag #	Channel	Macrotime	Microtime
2	0	0	0	18684
3	1	0	0	55740
4	2	0	0	92796
5	3	0	0	129852
6	4	0	0	166907
7	5	0	0	203958
8	6	0	0	241012
9	7	0	0	278066
10	8	0	0	315120
11	9	0	0	352173
12	10	0	0	389227
13	11	0	0	426280
14	12	0	0	463331

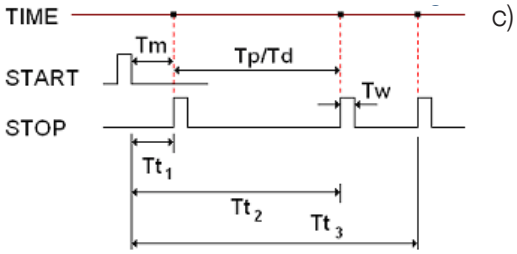
- Option 1: Free Running:

  Once acquisition started it carries on indefinitely

- Option 2: Re-Synch

  Acquisition is re-started at a rate of 250kHz.

c)



Tw	Min. START or STOP input pulse width	1.5ns
Td	Dead Time (time to process event)	190ns
Tt	LSB (timing resolution)	27ps
Tp	Min. time between STOPs	5.5ns
Tm	Minimum time from START to first STOP	5.2ns

* Although the time to process an event is 190ns, burst rates in excess of 100MHz are possible owing to a 256-deep FIFO. The average rate should not exceed ~5MHz.

Figure 8

In this mode the process is started with a single START pulse. The module will then fill the memory with time tags defining the time of each STOP event with relation to the initial single START pulse. Any further START inputs will be ignored. This mode is illustrated in Fig.8a and Fig.8c and is also referred to as '**Time Tagging**'. Data is saved as a .CSV file. A typical data file is shown in Fig.8b.

There is a further 'Re-Sync' option within this mode that uses a 250KHz clock output from the module as the START input. The clock continuously re-synchronizes the module to eliminate long term drift between channels. This is the preferred method when it is required to compare the data from more than one channel.

Note: In this mode all STOP events will be time-stamped and saved to memory. Each time-tag will be comprised of two 32-bit words. These two words will provide timing value, with a resolution of 27ps, and the channel ID. The memory will be configured as a large FIFO interfacing to the USB interface. Suitable handshake signals are implemented allowing continuous transfer of these time-tags from the FIFO to the PC via the USB port. Hence, in this mode, continuous time tagging to the host PC can be achieved indefinitely.

SensL Integrated Environment (SIE)

The SIE is a user interface for setting up and controlling the HRM-TDC module. While the interface provides an extensive range of operating modes and measurement processes, including graphical presentation, it does not fully cover all features available in the HRM-TDC module.

The SIE communicates with the module via a low level DLL. This DLL has been designed to provide a set of functions that will allow full control of the HRM-TDC for all features. For complex experiments that require control beyond the scope of the SIE, it is expected that the user will write their own real-time application utilizing the various function in this DLL. For details of the DLL functions, see the Appendix in this document.

SYSTEM REQUIREMENTS

- Windows XP SP2 operating system
- 1 GByte of RAM
- At least one spare High Speed USB 2.0 port
- .NET Framework installed (included)
- JAVA runtime environment installed (included)
- Microsoft Visual C++ runtime components (included)

INSTALLATION

To install the TDC software and USB drivers, follow these steps:

- Go to www.sensl.com/support/sw/ and download both the 'Release Note' PDF and the 'HRM-TDC Software' EXE files.
- Run the **HRM-TDC_Install_XpXX.exe** (where the XpXX is the revision number) file and follow the instructions. After the GUI and DLLs are installed, you will be prompted to install QuickUSB drivers which are necessary for communication with the TDC.
- Now power up the HRM-TDC module and connect the USB cable.
- The PC will recognize that new hardware has been added. Depending on the operating system the drivers may be located automatically, or it may be necessary to select them manually by directing the PC to the directory c:\Program Files\SensL\HRM-TDC\QuickUSB* where the necessary file will be located.
- The PC is ready to launch the TDC software. It can be found in the directory C:\Program Files\SensL\HRM-TDC *

* This assumes you have used the default directory settings for your installation.

USING THE SENSL INTEGRATED ENVIRONMENT (SIE)

Main Page

When the SIE software is launched it will search the USB for available HRM-TDC modules and initialize them ready for use. Once this has been carried out the main SIE page will appear as shown in Figure 9. A list of available devices will be shown. To inspect and select the various operating modes available, right click on the module name and then select the particular mode you require (see Fig. 9).

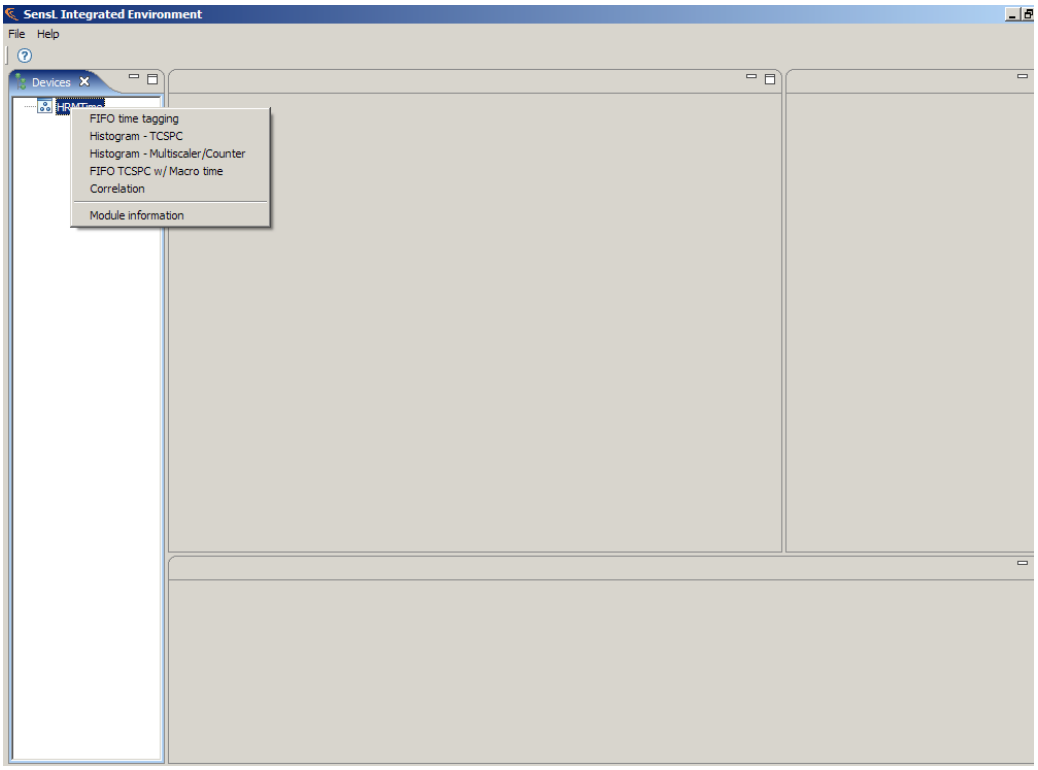


Figure 9 SIE Main Page screen

Module Information

This page displays the configuration information unique to this module. This information includes the module ID number and the various measurement modes. This page also allows the user to upgrade the internal FPGA image.

To upgrade the FPGA image the user must first click on the Update FPGA button. This will launch the Update Wizard as shown in Figure 10. Use the Browse button to find the RPD file for upgrading. Finally click the Update Device button to start the upgrade.

WARNING:

USB communication must be maintained during this process. Do NOT disconnect the USB cable during the update.

Updating the FPGA should only be carried out if you are instructed to do so by SensL. This procedure requires a valid RPD file as provided by SensL.

Failure to carry out this process correctly may render the module inoperable resulting in the need to return it to SensL for reconfiguration.

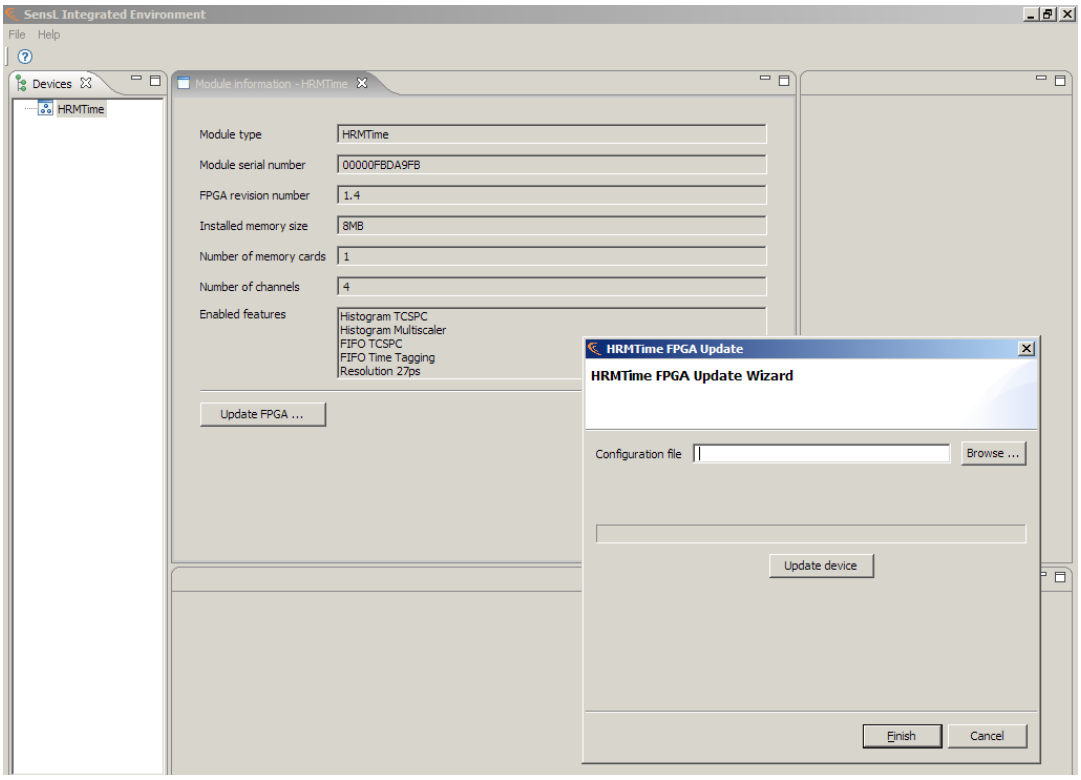


Figure 10 SIE Module Information screen

"HISTOGRAM –TCSPC" (Histogram Single-stop)

When this page is launched the top half will display a graph page. Left click on this graph to reveal the configuration settings. The size of the configuration and graph area can be adjusted by dragging the partition to suite. Figure 11 show this page with the partition adjusted to reveal the entire configuration controls.

Programmable Clock Output

The Programmable Clock Output is made available for all modes and is used to set the frequency and duty cycle of the internal programmable clock. This clock is available at an SMA output for test purposes. This clock is provided for testing and diagnostics. The clock will exhibit a level of jitter that would not be suitable for accurate measurements as part of an experiment.

External Clock Period

This should be set to the period of the external LASER clock.

Reverse Plot

Due to the method of TCSPC measurement, where the start and stop events are reversed, it is sometimes useful to plot the curves with the TIME axis reversed. Selecting this option will reverse the time axis for the plot.

Show Time Bins as Bars

Selecting this option will result in the graphical output being displayed as histogram bars rather than as a single best fit line as shown in Fig 11.

Microtime LSB

The smallest bin width is 27ps. In some cases it may not be necessary to be this accurate. Selecting the LSB of the microtime defines the bin resolution. Bit 0 is the highest resolution of 27ps. Bit 1 will set the bin width to 54ps (2 x 27) bit 2 will set the bin width to 108ps (4 x 27) and so forth.

The choice of bin width is application specific. Should the experiment not require such accuracy it may be better to select a lower resolution than 27ps. This will give the added advantage of allowing a wider time range over the available memory and/or more room for multiple curves.

Channel Enable and Edge Selection

These check boxes allow the individual channels to be enabled/disabled and the sensitivity of the START/STOP inputs to be specified.

Note: Press the **Apply changes** button to set your selected configuration.

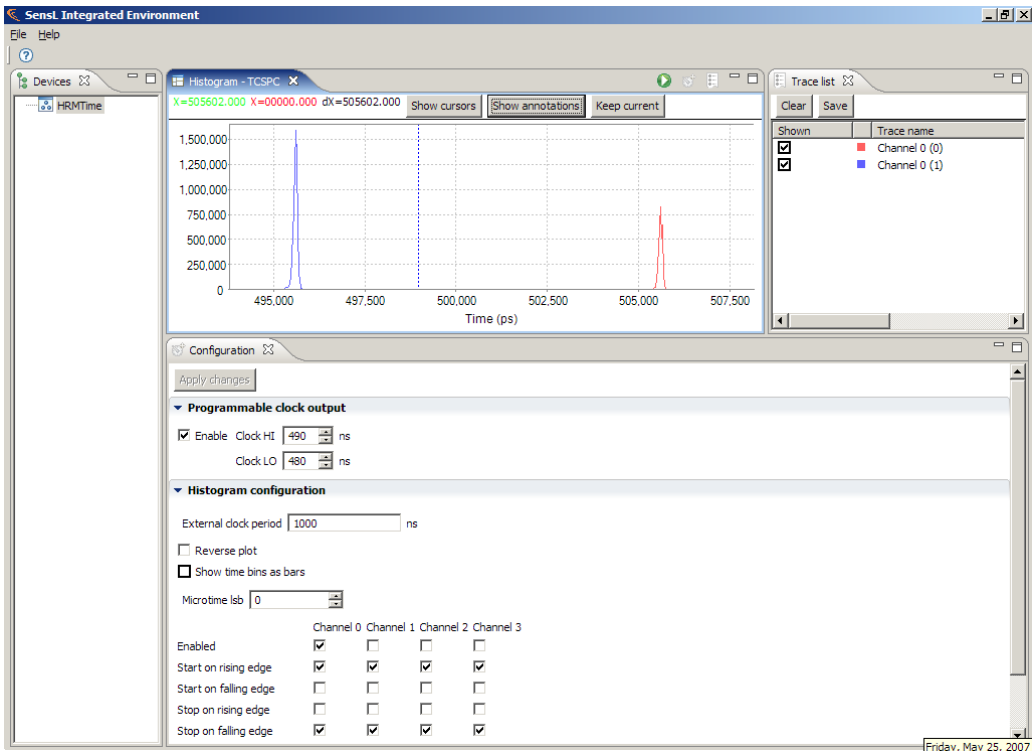


Figure 11 SIE Histogram TCSPC screen

Graphical Presentation

Once the configuration is selected, the configuration page can be removed by clicking on the X tab to display the graph section only (see Figure 12).

To start processing, click on the green right arrow at the top of the page. This can be done numerous times to display multiple traces on the same graph. Fig 11 shows the result of a simple TCSPC experiment. The right hand side of the display shows the traces. In this case two traces are displayed both from channel0. These traces can be saved to file or cleared by selecting them with the relevant checkbox and using the save and clear buttons.

Once the processing has been stopped, the graph can be analyzed.

To zoom in, hold right mouse button down and size selection box over area of interest.

To zoom out, sweep mouse from right to left with right mouse button held down.

To measure between points, click on the graph with right button and left button to position the two cursors. The position of these two cursors and their X and Y differences will be displayed at the top of the graph (see Fig 12).

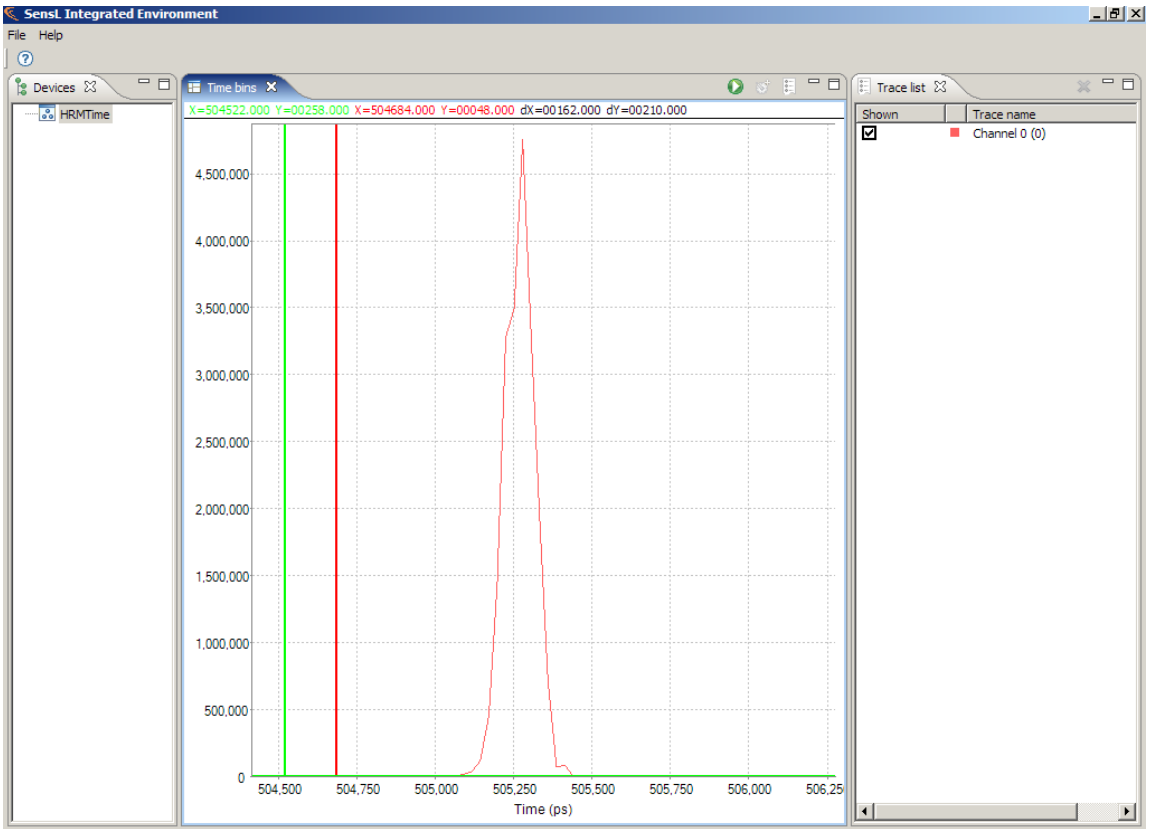


Figure 12 SIE Histogram - TCSPC, graph section only

"HISTOGRAM – Multi-scaler" (Histogram Multi-stop)

When in this mode the configuration setup and operation is identical to the HISTOGRAM-TCSPC mode. In TCSPC mode the system repeatedly plots the time of the first event after a LASER pulse. In Multi-scaler/Counter mode the operation is very different. The start event is a slow clock of less than 7MHz. The system records and saves all stop

events in their respective time bins. Each start event will reset the timer and a new set of stop events will be added to the existing array of time bins. This process will result in a histogram being built up of all the events following the start. This is particularly useful for plotting pulse shapes, decay curves etc.

"FIFO – TCSPC with MACRO time" (FIFO Single-stop)

When this page is launched the top half will display a graph page. Left click on this graph to reveal the configuration settings. The size of the configuration and graph area can be adjusted by dragging the partition to suite.

This page is a graphical demonstration of the TCSPC with MACRO time feature of the HRM-TDC module. The HRM-TDC allows the user to carry out TCSPC and save time tags. These time tags consist of the TCSPC measurement plus a MACRO time defining at what time during the experiment the measurement was made. For normal operation, this feature would use data streaming that would allow the user to continually record time-tags indefinitely to a PC file. This mode of the SIE records for a given period or until the HRM-TDC memory is full.

Programmable Clock Output

The Programmable Clock Output is made available for all modes and is used to set the frequency and duty cycle of the internal programmable clock. This clock is available at an SMA output for test purposes. This clock is provided mainly for testing and diagnostics. The clock will exhibit a level of jitter that would not be suitable for accurate measurements as part of an experiment.

Recording Length

The recording length should be set to the desired period over which the TCSPC measurements are to be taken. Note that the processing will stop prematurely if the Maximum Event Count is reached.

Maximum Event Count

This defines the maximum number of events to be stored before recording stops. This value is used to ensure the storage data size does not exceed the capacity of the system.

External Clock Period

This should be set to the period of the external LASER clock.

Reverse Plot

Due to the method of TCSPC measurement, where the start and stop events are reversed, it is sometimes useful to plot the curves with the TIME axis reversed. Selecting this option will reverse the time axis for the plot.

Macro and Micro Time Configuration Selection

These fields allow the user to select the number of MACRO and MICRO bits and resolution to appear in the 32-bit time tag word. As bit counts and resolution are changed the resulting roll over times and resolution values will be automatically displayed in the boxes to the right hand side. If the user attempts to input an illegal value the relevant text boxes will turn red.

Channel Enable and Edge Selection

These check boxes allow the individual channels to be enabled/disabled and the START/STOP inputs sensitivity to be specified.

Note: Press **Apply changes** button to set your selected configuration.

Data Recording

Once the configuration is selected, the mode is now ready for recoding data. In FIFO – TCSPC mode two forms of data recording are available, Graphical Presentation and Streaming TCSPC Time Tags.

Graphical Presentation

In this mode recording is carried out at the module until the recording length or the maximum event count is reached. To start processing, click on the green right arrow at the top of the page. Figure 13 shows the result of a simple experiment. The right hand side of the display will show which channels are active. In this example only channel 0 is active.

After starting the experiment the module will run for the Recording Length or until the memory is full. Once the process has stopped the top graph will display a plot of the event frequency over time. The user can now use the cursors to select a time period of the top graph. When this is done the software will automatically plot the TCSPC curve for the time tags over that particular period.

The user can, at any time, save these curves and run the experiment again. Fig 13 shows an example of this mode of operation. The user can, for each run, save a particular TCSPC curve or set of curves and compare it with other curves at different MACRO time ranges and/or runs.

Once the processing has been stopped, the graphs can be analyzed.

To zoom in, hold right mouse button down and size selection box over area of interest.

To zoom out, sweep mouse from right o left with right mouse button held down.

To measure between points click on graph with right button and left button to position two cursors. The position of these two cursors and their X and Y differences will be displayed at the top of the graph (see Fig 13).

This mode of operation is particularly useful for carrying out preliminary tests to determine the best configuration, before carrying out a full experiment using continuous streaming of results to a PC file.

Streaming TCSPC Time Tags

Once the configuration is selected, the user can now select a path and file name for saving the data. It is recommended that the file name have a suffix of CSV. Doing this will allow the file to be easily viewed using a spreadsheet package. Once this is done the process can be started by clicking the Start button. Clicking the Start button will start the module streaming all time tags to the chosen file until the recording time is reached, the maximum event count is reached or the process is manually stopped.

After the process is stopped the file will be available for viewing. Figure 14 shows a section of a typical output file.

As can be seen in Fig 14, four columns are used to define the tag number, channel ID, macro time and micro time.

The example experiment used the test waveform set to 1MHz with a 50% duty cycle. This signal was fed directly into both the start and stop inputs of channel 0. The start was set to trigger on the LO-HI transition and the stop

was set o trigger on the HI-LO transition. As can be seen in Fig 14, the time-tags are repeating every 200 counts of the MACRO time. As the resolution of the MACRO time was set to 5ns, this represents a repetition rate of 1μs (200 x 5 ns). The TCSPC time is typically 18712. As the resolution of the MICRO time was set to 27ps, this represents a TCSPC MICRO time of ~505ns (18712 x 27ps). The value of 505ns rather than the theoretical value of 500ns is due to the jitter of the clock and the quality of the cabling.

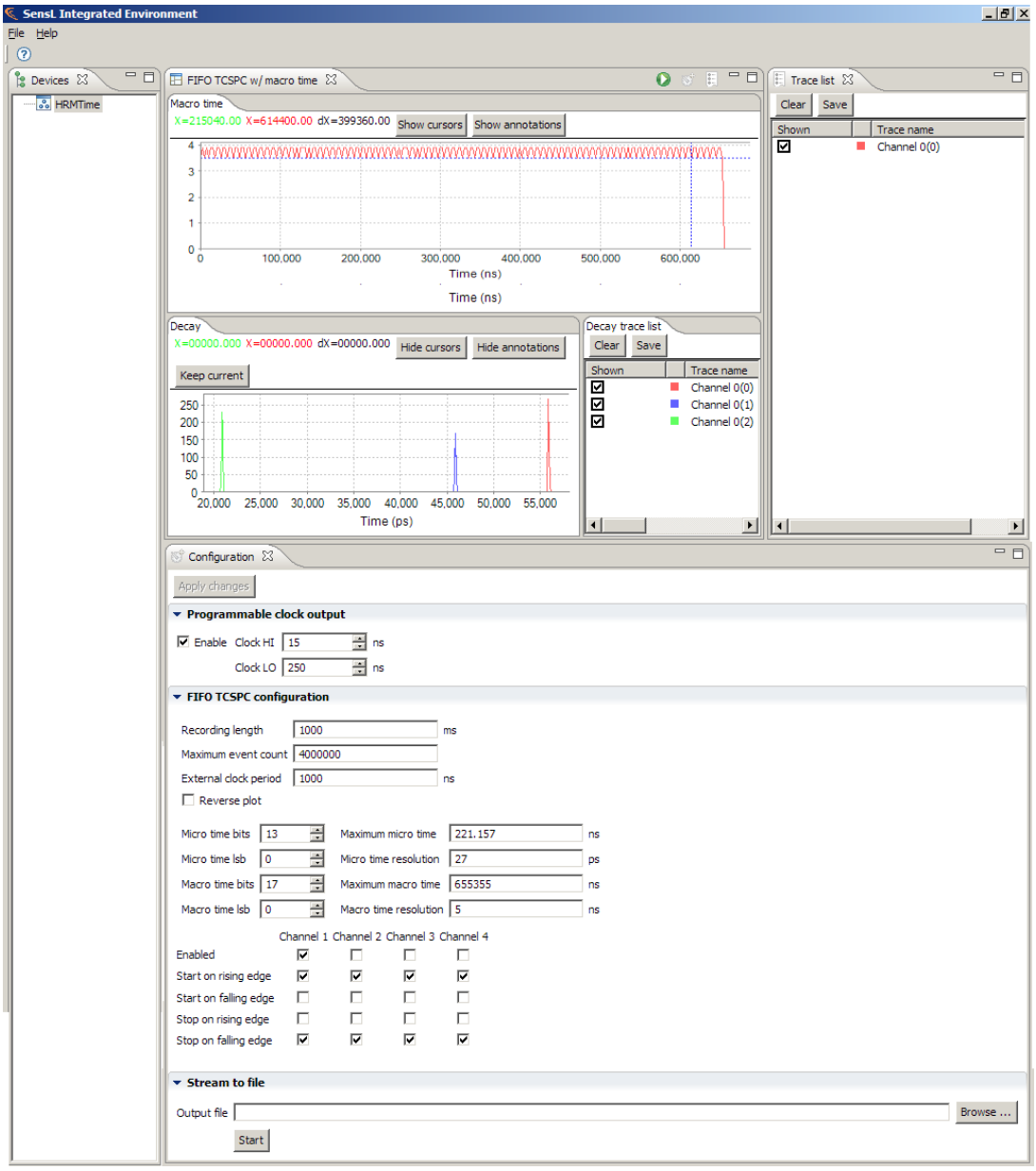
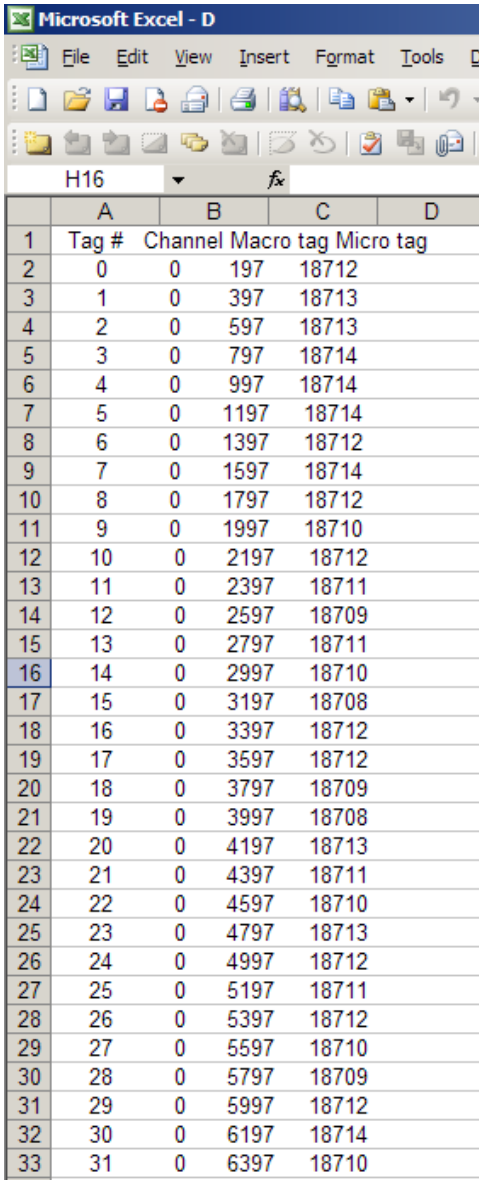


Figure 13 SIE showing the "FIFO - TCSPC with Macro Time" screen



	A	B	C	D
1	Tag #	Channel	Macro tag	Micro tag
2	0	0	197	18712
3	1	0	397	18713
4	2	0	597	18713
5	3	0	797	18714
6	4	0	997	18714
7	5	0	1197	18714
8	6	0	1397	18712
9	7	0	1597	18714
10	8	0	1797	18712
11	9	0	1997	18710
12	10	0	2197	18712
13	11	0	2397	18711
14	12	0	2597	18709
15	13	0	2797	18711
16	14	0	2997	18710
17	15	0	3197	18708
18	16	0	3397	18712
19	17	0	3597	18712
20	18	0	3797	18709
21	19	0	3997	18708
22	20	0	4197	18713
23	21	0	4397	18711
24	22	0	4597	18710
25	23	0	4797	18713
26	24	0	4997	18712
27	25	0	5197	18711
28	26	0	5397	18712
29	27	0	5597	18710
30	28	0	5797	18709
31	29	0	5997	18712
32	30	0	6197	18714
33	31	0	6397	18710

Figure 14 Typical output data from streaming TCSPC Time Tags

"FIFO – Time Tagging" (FIFO – Multi-stop)

This page is used to continuously stream event time tags, as shown in Fig. 15. This mode offers 2 methods that are selected by the value of the programmable clock. If the programmable clock is set to 1280 HI and 1280 LO then the Resync option is selected. Any other clock value will select the Free Running option.

Free Running:

Once the configuration is selected, the user can start the module recording. The module will wait for the first single start pulse and then start recording every stop event until the recording time is reached, the maximum event count is reached or the process is manually stopped. The first start pulse will begin recording. All following stop events will be stamped and saved. Any following start pulses during the process will be ignored. Hence, all events, after the initial start signal, can be saved indefinitely.

Resync:

Using this method, the user must feed the programmable clock output to the Start input of any channel being used. Once the configuration is selected, the user can start the module recording. The module will wait for the first Start pulse and then start recording every stop event until the recording time is reached, the maximum event count is reached or the process is manually stopped.

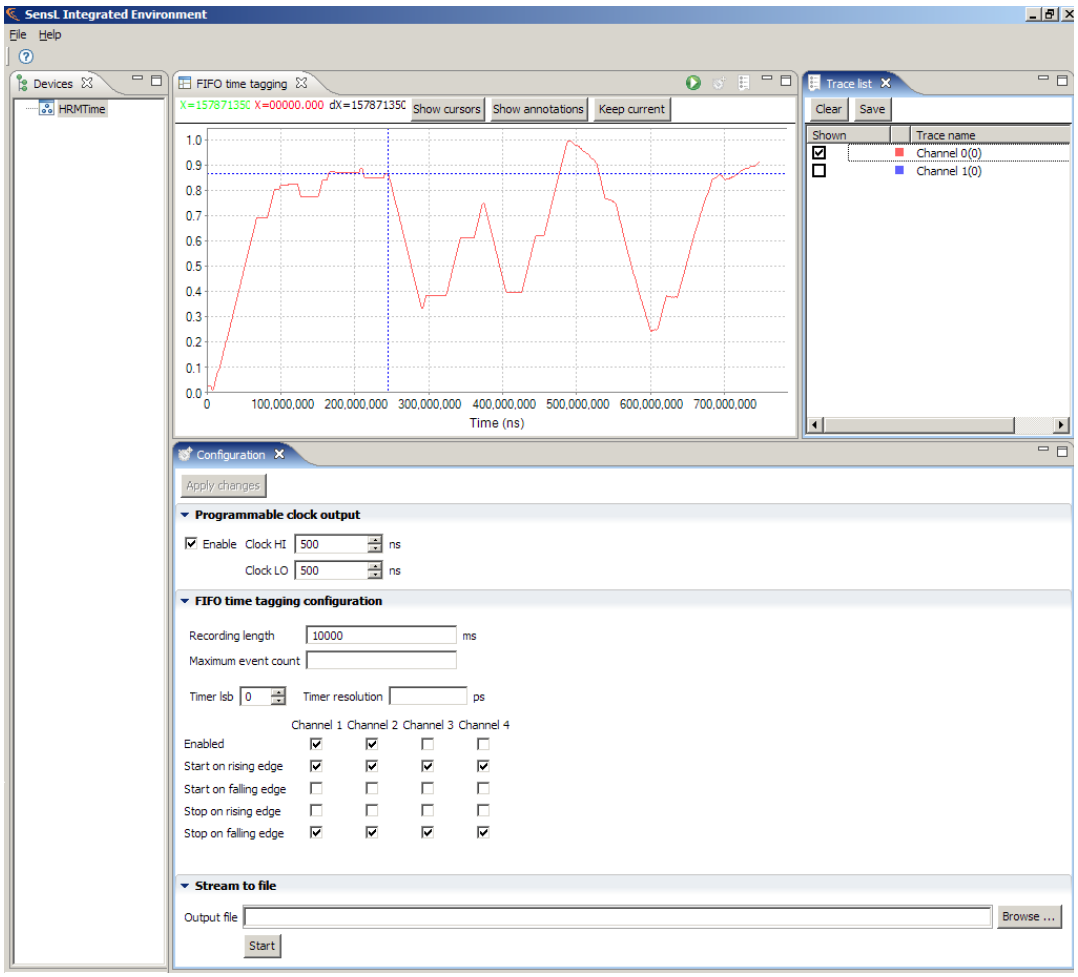


Figure 15 SIE screen for FIFO - Time Tagging

Programmable Clock Output

Free Running:

The Programmable Clock Output is made available for all modes and is used to set the frequency and duty cycle of the internal programmable clock. This clock is available an SMA output for test purposes. This clock is provided for testing and diagnostics only. The clock will exhibit a level of jitter that would not be suitable for accurate measurements as part of an experiment.

Resync:

With the clock programmed to 1280 HI, 1280 LO (FSR register set to 0xFFFF) the module will operate in Resync.

Recording Length

The recording length should be set to the desired period over which the TCSPC measurements are to be taken.

Maximum Event Count

This defines the maximum number of events to be stored before recording stops. This value is used to ensure the storage data size does not exceed the capacity of the system.

Timer LSB

This is used to select the resolution of the time tag. Selecting bit 0 will give the time tag a resolution of 27ps. Bit 1 will set the resolution to 54ps (2 x 27), bit 2 will set the resolution to 108ps (4 x 27) and so forth.

Channel Enable and Edge Selection

These check boxes allow the individual channels to be enabled/disabled and the START/STOP inputs sensitivity to be specified.

Note: Press the **Apply changes** button to set your selected configuration.

Data Recording

Once the configuration is selected, the mode is now ready for recoding data. In FIFO – Time Tagging mode two forms of data recording are available, Graphical Presentation and Streaming FIFO Time Tags.

Graphical Presentation

In this mode recording is carried out at the module until the recording length or the maximum event count is reached. To start processing, click on the green right arrow at the top of the page. The right hand side of the display will show which channels are active. On completion the graph will display a plot of event density (frequency) over time.

This mode of operation is particularly useful for carrying out preliminary tests to determine the best configuration, before carrying out a full experiment using continuous streaming of results to a PC file.

Streaming FIFO Time Tags

Once the configuration is selected, the user can now select a path and file name for saving the data. It is recommended that the file name have a suffix of CSV. Doing this will allow the file to be easily viewed using a spreadsheet package. Once this is done the process can be started by clicking the Start button. Clicking the Start button will start the module streaming all time tags to the chosen file until the recording time is reached, the maximum event count is reached or the process is manually stopped. In this mode there is no TCSPC. The first start pulse will begin recording. All following stop events will be stamped and saved in the target PC file. Hence, all events, after the initial start signal, can be saved to file indefinitely.

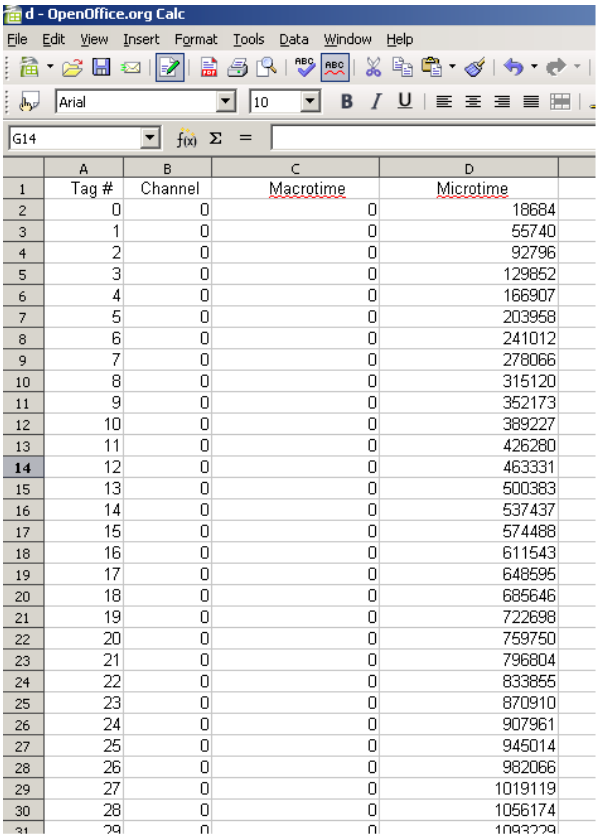
After the process is stopped the file will be available for viewing. The format of the output file will differ depending on whether the mode used the Free Running or Resync option. Figure 16 shows a section of a typical output file for both options.

As can be seen in Fig. 16, four columns are used to define the tag number, channel ID, macro time and micro

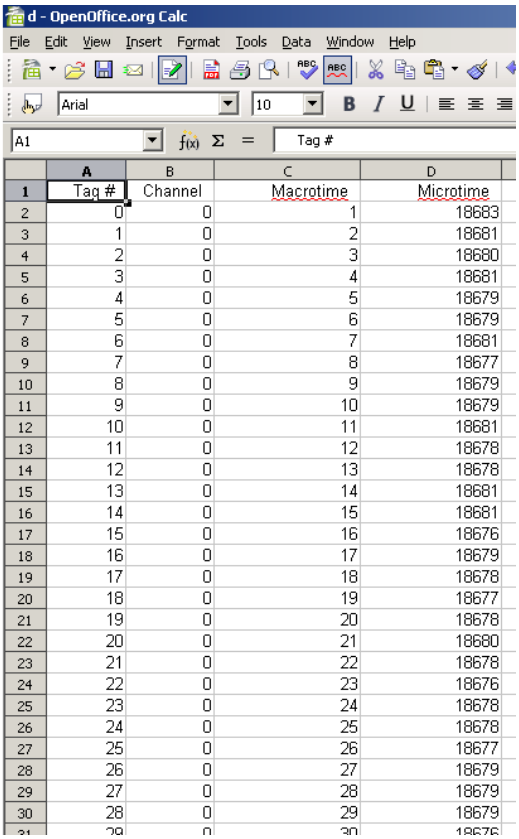
time.

The time tag for this mode consists of 2 x 32-bit words. The first word is a micro time that has a resolution down to 27ps. Using the Free Running option this timer will roll over at the count of 5308415 (Hex 50FFFF). Using the Resync option this timer will roll over every 4 microseconds. In both cases the MACRO counter is a count of how many times the MICRO counter has rolled over.

Note: The LSB value of 27ps is not an exact value. This value is a simplified (rounded up) value that is suitable for all other modes. The true LSB value is 26.9851ps. As this mode involves the continuous running of the MICRO clock for very long periods it is recommended that the value of 26.9851 is used to avoid a cumulative error occurring over long periods of time.



	A	B	C	D
1	Tag #	Channel	Macrotime	Microtime
2	0	0	0	18684
3	1	0	0	55740
4	2	0	0	92796
5	3	0	0	129852
6	4	0	0	166907
7	5	0	0	203958
8	6	0	0	241012
9	7	0	0	278066
10	8	0	0	315120
11	9	0	0	352173
12	10	0	0	389227
13	11	0	0	426280
14	12	0	0	463331
15	13	0	0	500383
16	14	0	0	537437
17	15	0	0	574488
18	16	0	0	611543
19	17	0	0	648595
20	18	0	0	685646
21	19	0	0	722698
22	20	0	0	759750
23	21	0	0	796804
24	22	0	0	833855
25	23	0	0	870910
26	24	0	0	907961
27	25	0	0	945014
28	26	0	0	982066
29	27	0	0	1019119
30	28	0	0	1056174



	A	B	C	D
1	Tag #	Channel	Macrotime	Microtime
2	0	0	1	18683
3	1	0	2	18681
4	2	0	3	18680
5	3	0	4	18681
6	4	0	5	18679
7	5	0	6	18679
8	6	0	7	18681
9	7	0	8	18677
10	8	0	9	18679
11	9	0	10	18679
12	10	0	11	18681
13	11	0	12	18678
14	12	0	13	18678
15	13	0	14	18681
16	14	0	15	18681
17	15	0	16	18676
18	16	0	17	18679
19	17	0	18	18678
20	18	0	19	18677
21	19	0	20	18678
22	20	0	21	18680
23	21	0	22	18678
24	22	0	23	18676
25	23	0	24	18678
26	24	0	25	18678
27	25	0	26	18677
28	26	0	27	18679
29	27	0	28	18679
30	28	0	29	18679

Figure 16 Data from Free Running mode *Data from Resync mode*

Example: If the MACRO time value is 28 and the MICRO time is 11232 then the absolute time of the tag from the start pulse is:

Free Running

((28 x 5308416) + 11232) x 26.9851ps = 4011250921ps.

Note: 5308416 = Hex 510000.

Resync

(28 x 4000000) + (11232 x 26.9851) = 112303097 ps.

Note: Rollover is every 4000000 ps.

Correlation

The Correlation feature allows the user to carry out cross and auto correlation on FIFO-TCSPC streams for both the TCSPC values and the MACRO times. The correlation screen is shown in Fig. 17.

In Correlation mode the configuration setup is identical to FIFO-TCSPC mode. However, channel select is restricted to a maximum of two channels. A single channel selected will result in auto-correlation on that input. Two channels will result in cross-correlation on the two channels. Further correlation specific settings are as follows:

Target Data Set

Use these two mutually exclusive radio buttons to select correlation on the MICRO (TCSPC) or MACRO time.

Bin Size/Resolution

This setting determines the bin size to be used for the correlation function. Increasing this value will direct the correlation function to group greater numbers of consecutive time tags into software bins. These bins are then used for phase sweeping the streams to create the correlation curve.

Maximum Lag

This defines the maximum number of bins to be used for carrying out the correlation algorithm.

Graphical Presentation

Once the configuration is selected, the mode is now ready for recording data. In this mode recording is carried out at the module until the recording length or the maximum event count is reached. To start processing, click on the green right arrow at the top of the page.

After starting the experiment the module will run for the Recording Length, the maximum event count is reached or until the memory is full. Once the process has stopped the top graph will display a plot of the event frequency over time. The bottom graph will display the correlation curve as specified by the configuration parameters. For details of the correlation algorithm see the Appendix in this document.

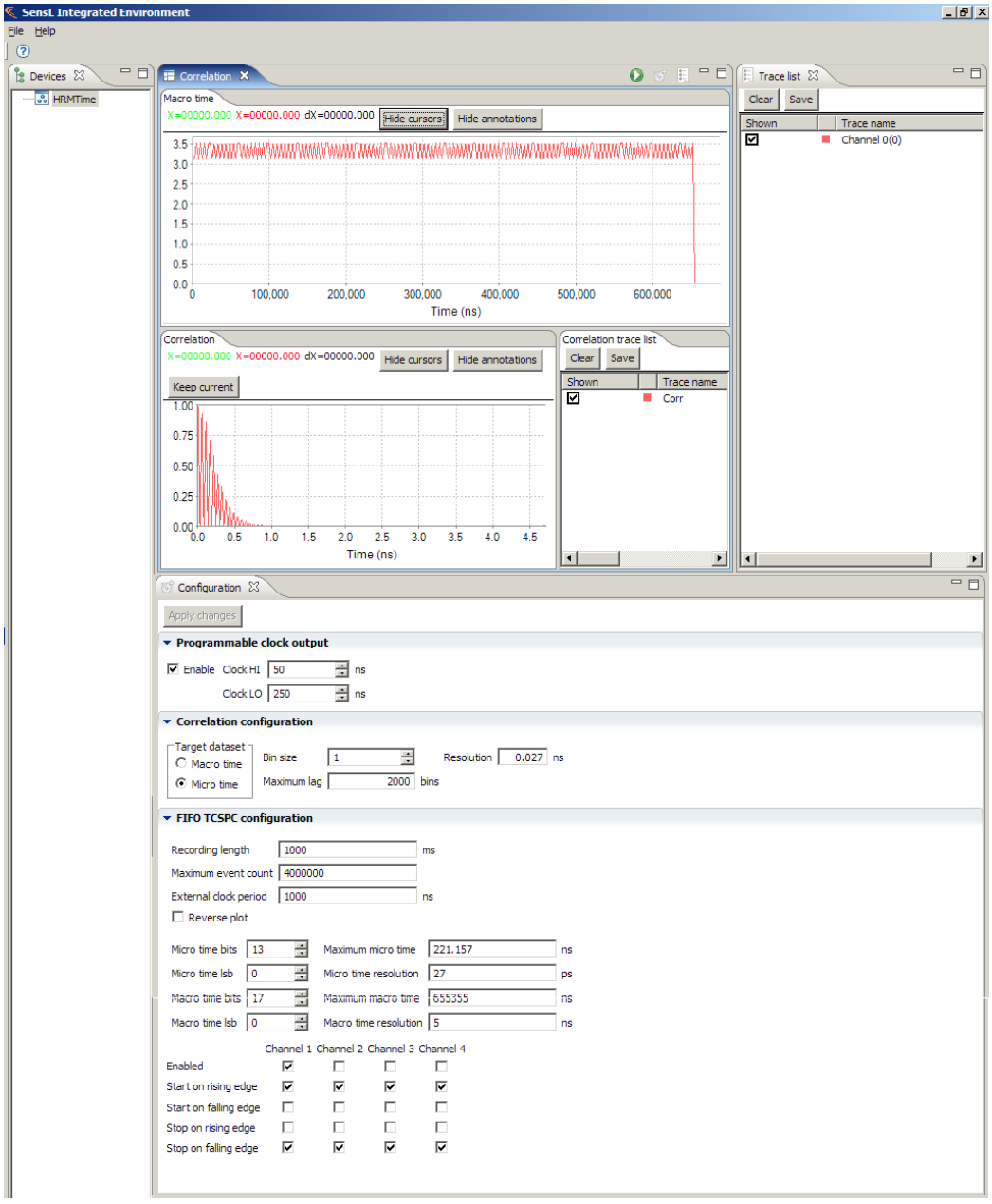


Figure 17 SIE Correlation screen

Appendix

HRM-TDC REGISTERS AND LOW LEVEL DLL FUNCTIONS

The control and setup of the HRM-TDC is carried out by a series of commands to a set of configuration registers within the module. To simplify the control of these registers, a set of low level drivers, in a DLL, is available. The low level drivers will return an HRM_STATUS of value HRM_OK or HRM_ERROR.

For standard 'C' programming the user must use the DLL HRMTimeAPI.DLL
For LabVIEW the user must use the modified version of the DLL providid called HRMTimeALI_LV.DLL
In both cases a copy of the relevant DLL **MUST reside in the same folder as the application**.

Initialization Low Level Drivers

Before the user can read/write to these configuration registers communication must be established with the module. To do this the following low level driver functions must be used.

Driver - HRM_GetDLLVersion

HRM_API const char* WINAPI HRM_GetDLLVersion(void)

This function returns a pointer to a text string describing the revision level of the drivers.

Driver - HRM_SetConfigurationPath

HRM_API void WINAPI HRM_SetConfigurationPath(char* path)

path: Pointer to text string defining path.

This function is used to define the path where the configuration data for the module resides.

Driver - HRM_RefreshConnectedModuleList

HRM_API bool HRM_RefreshConnectedModuleList(void)

This function can be called at any time to determine if the list of connected modules has changed. This can be used to periodically poll the USB bus to determine if modules have been connected or disconnected.

Driver - HRM_GetConnectedModuleCount(void)

HRM_API UINT WINAPI HRM_GetConnectedModuleCount(void)

This function is used to determine how many HRM-TDC modules are currently connected to the USB bus.

Driver - HRM_GetConnectedModuleList

HRM_API void WINAPI HRM_GetConnectedModuleList(HANDLE* handleList)

handleList: Pointer to array of HRM-TDC handles for initialization.

This function initializes an array of HRM-TDC handles to allow communication with all HRM-TDC modules present on the USB bus. The size of the array must be greater or equal to the number of modules detected using the function HRM_GetConnectedModuleCount.

Driver - HRM_CloseModule

HRM_STATUS WINAPI HRM_CloseModule(HANDLE handle)

On completion of the application, this function must be called to release the handle and close the session.

Example:

```
   int         moduleCount;
   HANDLE      handleArr[20];
HRM_RefreshConnectedModuleList();
moduleCount = HRM_GetConnectedModuleCount();
   if(moduleCount)
   {
HRM_GetConnectedModuleList(handleArr);
APPLICATION CODE HERE
HRM_CloseModule(handleArr);
}
else
    printf("No HRM-TDC modules detected");
```

In this example the `APPLICATION CODE` can address up to **'moduleCount'** HRM-TDC modules.

Now that communication with the module has been established the configuration registers can be programmed using the associated low level driver.

ARR – Address Route Register

Register Description

The method of time-binning is based on using the received time-tag data and discrete I/O inputs to form the address in memory for time-bin processing. In its simplest form, a time-tag could be used as the address bus so that each time-bin is separated by the resolution of the least significant bit. On receipt of a time-tag the system outputs the time-tag as an address and then increments that location (time-bin). In the HRM-TDC system further data bits are included in the address selection to allow multiple curve plotting based on multiple channel inputs and discrete inputs for X, Y array plotting. To allow maximum flexibility the AAR register can define any bit to be placed in any

position within the address bus for the shared memory.

Understanding the ARR is critical as it is the controller that defines the resolution, curve count and array size of all measurements.

Before programming the ARR the user must first assert an RRR (Route Register Reset) command to initialize the system. Once this is done the ARR is then programmed by sending 27 consecutive writes. The address bus of the memory is 27 bits (A26-A0). Starting with A0, each write defines the bit number of the 'Address Option Bits' to be routed to that particular address bit. The 'Address Option Bits' are as follows:

AOB[24.. 0]	TagData
AOB[51..25]	Address Counter
AOB[67..52]	16-bit I/O Data
AOB[79..68]	Pixel Counter
AOB[91..80]	Line Counter
AOB[92]	Fix to logic 0

TagData

This is the time-tag data as received by the Pico-Second Timing Interface. Bits 23,24 define on which channel the time-tag was received – 00, 01, 10 or 11. The bits 22 down to 0 define the time with bit 0 being the LSB (LSB = 26.9851ps).

Address Counter

These bits provide a 27-bit counter that can be routed to the address bus. This counter can be pre-loaded with a given value. After each write to memory this counter will be automatically incremented. This counter would be most used when the system is in time-tag mode. Here the system reads time-tags and stores them in consecutive locations in memory. These bits are also available to be used in Time-bin mode. However, in this case the address is not incremented. Instead the address counter bits are used purely as an offset address in memory for saving curves.

16-Bit I/O Data

The value of the 16 I/O data bits can be routed to any address line. This would be useful for plotting X, Y curves. For example, the I/O could be used as 8-bit X and 8-bit Y inputs allowing a 256 x 256 array of curves to be plotted.

Pixel Counter/Line Counter/Frame Reset

The 16-bit I/O method of X,Y plotting is limited to 256 x 256 arrays. An alternative method that allows larger arrays is to use 2 discrete inputs to clock counters that in turn can be used as the address in memory. The HRM-TDC module provides a 12-bit Pixel Counter and a 12-bit Line Counter. The Pixel Counter is incremented by clock inputs to IODATA(0) and the line counter is incremented by clock inputs to IODATA(1). If these bits are routed to the address lines then the user can command the HRM-TDC module to move from one curve to the next by clocking the IODAT(0) and IOADAT(1) lines. This allows arrays of up to 4096 x 4096.

The contents of the LINE and PIXEL counters are cleared when:

1. A write is sent to the **Routing Reset Register** (RRR)
2. A LO-HI transition is detected on the **IODATA(2)** port.

The IODATA(2) can be used as a Frame Reset clock input for synchronizing an X,Y pixel image with an external instrument such as a microscope.

Fix to logic 0

Selecting this bit will drive the particular address line low. This is used for driving the chip select line of a single memory card. If two memory cards are used then the chip select should be an address counter bit.

Example:

WRITE: 1,2,3,4,5,6,7,8, 23,24, 25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41

This would set up the system recording 4 curves, one from each channel. Each curve would consist of 256 bins (8 bits) with a bin size of 54ps. This reduced resolution is due to bit 1 (second bit) of the time-tag being routed to address bit 0. The channel bits 23, 24 will move each channel event to a different curve. The base start address of these curves will be defined by the pre-programmed value of the **Address Counter**.

Driver - HRM_SetAddressRouteRegister

HRM_STATUS WINAPI HRM_SetAddressRouteRegister(HANDLE handle, BYTE* arrData)

handle: HRM-TDC module handle

arrData: Array of bytes to write to the address route register.

Note:

The **arrData** bytes must be padded with 0 values after each routing value. Therefore, for the example, the **arrData** array must be set to:

1,0,2,0,3,0,4,0,5,0,6,0,7,0,8,0,23,0,24,0,25,0,26,0,27,0,28,0,29,0,

30,0,31,0,32,0,33,0,34,0,35,0,36,0,37,0,38,0,39,0,40,0,41,0

DRR – Data Route Register

Register Description

When the HRM-TDC system is in time-tag mode it will continually save time-stamps to memory. Each time-stamp will always be 32-bits, however the format of the time-stamp is programmable using the DRR. To allow maximum flexibility the DRR register can define any 'Data Option Bit' bit to be placed in any position within the 32-bit time-tag.

Before programming the DRR the user must first assert an RRR (Route Register Reset) command to initialize the system. Once this is done the DRR is then programmed by sending 32 consecutive writes. Starting with D0, each write defines the bit number of the 'Data Option Bits' to be routed to that particular data bit within the time-tag. The 'Data Option Bits' are as follows:

DOB[24.. 0]	TagData
DOB[56..25]	Macro Counter
DOB[57]	Fix to logic 0

TagData

This is the time-tag data as received by the Pico-Second Timing Interface. Bits 23,24 define the channel the time-tag was received on – 00, 01, 10 or 11. The bits 22 down to 0 define the time with bit 0 being the LSB (LSB = 26.9851ps).

Macro Counter

When time-tag recording the user may, along with the TCSPC time, wish to record the chronological time that the event occurred. A 32-bit Macro Time Counter is made available that is cleared at the start of time-tag processing and will increment every 5ns. The user can select a range of these bits to provide a macro time to time-stamp each time-tag.

Example:

WRITE: 0,1,2,3,4,5,6,7 26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47 23,24

This would set up the time-tag as follows:

D[7..0]	=	TCSPC time (LSB = 26.9851ps)
D[29..8]	=	22-bit Macro time with LSB resolution of 5ns
D[31..30]	=	2-bit channel code 00, 01, 10, 11 for channels 0 to 3.

Driver - HRM_SetDataRouteRegister

HRM_STATUS WINAPI HRM_SetDataRouteRegister(HANDLE handle, BYTE* drrData)

handle: HRM-TDC module handle

drrData: Array of bytes to write to the data route register.

Note:

The **drrData** bytes must be padded with 0 values after each routing value. Therefore, for the example, the **drrData** array must be set to:

0,0,1,0,2,0,3,0,4,0,5,0,6,0,7,0,26,0,27,0,28,0,29,0,30,0,31,0,32,0,33,0,34,0,

35,0,36,0,37,0,38,0,39,0,40,0,41,0,42,0,43,0,44,0,45,0,46,0,47,0,23,0,24,0

LAL, LAH – Load Address LO/HI Register

Register Description

These two registers are used to initialize the '**Address Counter**' (see ARR register) to a pre-defined value. The order of loading the initialization address must be LAL followed by LAH. The LAL command will define the least significant 16 bits (A15 down to A0) of the counter. The least significant 11 bits of the LAH command will define counter bits A26 down to A16. On completion of the LAH command the '**Address Register**' will be loaded with the new value.

Driver - HRM_SetAddressRegister

HRM_STATUS WINAPI HRM_SetAddressRegister(HANDLE handle, ULONG arData)

handle: HRM-TDC module handle

arData: 32-bit address to set LAH, LAL to.

LFL, LFH – Load Fill Value LO/HI Register

Register Description

The user can command the HRM-TDC module to fill a range of memory with a given value. The value used for this command is defined using these 2 commands. The initialization value is a 32-bit value. The most significant 16 bits is defined by LFH and the least significant 16 bits is defined bits LFL.

Driver - HRM_SetFillValueRegister

HRM_STATUS WINAPI HRM_SetFillValueRegister(HANDLE handle, ULONG fvrData)

handle: HRM-TDC module handle

arData: 32-bit value to set LFH, LFL to.

UAL, UAH – Load Address LO/HI Register

Register Description

These two registers are used to initialize the USB address counter. The block DMA transfers from memory to the USB start at the address defined by these two commands. On completion of each USB transfer the USB address counter is automatically incremented. This address is a 32-bit **'long word'** address. All USB block transfers are carried out in long words (4 bytes at a time). The order of loading the initialization address **must** be UAL followed by UAH. The UAL command will define the least significant 16 bits (A15 down to A0) of the counter. The least significant 10 bits of the UAH command will define counter bits A25 down to A16. On completion of the UAH command the 'Address Register' will be loaded with the new value.

UAL:

D15	D14	D13	D12	D11	D10	D09	D08	D07	D06	D05	D04	D03	D02	D01	D00
A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0

UAH:

D15	D14	D13	D12	D11	D10	D09	D08	D07	D06	D05	D04	D03	D02	D01	D00
Nu	Nu	Nu	Nu	Nu	Nu	A25	A24	A23	A22	A21	A20	A19	A18	A17	A16

Driver - HRM_SetUSBAddressRegister

HRM_STATUS WINAPI HRM_SetUSBAddressRegister(HANDLE handle, ULONG uarData)

handle: HRM-TDC module handle

uarData: 32-bit address to set UAH, UAL to.

MBR – Mode Bits Register

Register Description

This register defines a number of settings for the HRM-TDC module as follows:

D15	D14	D13	D12	D11	D10	D09	D08	D07	D06	D05	D04	D03	D02	D01	D00
Rmd	Mem	Nu	Nu	Nu	Nu	Nu	Nu	Nu	BCe	Rvd	Rvd	Size	Md2	Md1	Md0

Md[2..0] These bits define in which mode the HRM-TDC module will operate.

000 = Fill 'n' memory locations with the **LFL,LFH** value.

The value of 'n' is defined by the **MCL,MCH** registers.

The start address is defined by the **LAL,LAH** registers.

001 = Run in TIME-TAG with TCSPC mode.

010 = Run in TIME-TAG continuous mode.

011 = Run in TIME-BIN with TCSPC mode.

100 = Run in TIME-BIN continuous mode.

All other Md[] combinations are reserved. Power-up default = 000.

Size

In TIME-BIN mode the bin size can be set for 16 bits or 32 bits. If 'Size' is set to '1' the bin size will be 16 bits. With 'Size' set to '0' the bin size will be 32 bits. Note that when the size is 16 bits the memory address defined by the ARR (Address Route Register) is a 16-bit word address. In all other cases the ARR shall define a 32-bit long words address.

Power-up default = 1

Rvd

Bits reserved. **Must be set to '1'.**

BCe

With this bit set to '1' the BINCNT (BCH, BCL) feature is enabled. If this bit is '0' then the effect of the BCH

and BCL is disabled.

Mem
This bit, when set to '1', will start the high speed USB memory or time-tag transfer processor. Taking this bit to '0', at any time, will immediately put the processor into reset.

Rmd
This bit, when set to '1' will start the mode processor. The mode of operation is defined by the Md bits. Taking this bit to '0', at any time, will immediately put the processor into reset.

Driver - HRM_SetModeBitsRegister

HRM_STATUS WINAPI HRM_SetModeBitsRegister(HANDLE handle, USHORT mbrData)

handle: HRM-TDC module handle

mbrData: 16-bit value to write to the MBR.

ESR – Edge Sensitivity Register

Register Description

All start and stop inputs can be programmed to produce an event on either a +Ve or -Ve transition. This register defines the edge sensitivity for each input as follows:

D15	D14	D13	D12	D11	D10	D09	D08	D07	D06	D05	D04	D03	D02	D01	D00
FN3	FP3	SN3	SP3	FN2	FP2	SN2	SP2	FN1	FP1	SN1	SP1	FN0	FP0	SN0	SP0

SP3, SP2, SP1, SP0 = Set to '1' for start event of corresponding channel on positive edge.
SN3, SN2, SN1, SN0 = Set to '1' for start event of corresponding channel on negative edge.
FP3, FP2, FP1, FP0 = Set to '1' for end event of corresponding channel on positive edge.
FN3, FN2, FN1, FN0 = Set to '1' for end event of corresponding channel on negative edge.

Note:

The positive and negative settings must never both be set to '1'. Only one edge is allowed.
To disable an input, set both the negative and positive bits to '0'.

Driver - HRM_SetEdgeSensitivityRegister

HRM_STATUS WINAPI HRM_SetEdgeSensitivityRegister(HANDLE handle, USHORT esrData)

handle: HRM-TDC module handle

esrData: 16-bit value to write to the ESR.

RRR – Routing Reset Register

Register Description

A write to this register:

Resets the ARR and DRR registers ready for programming

Clears the WCH and WCL registers

Clears the LINE and PIXEL counters.

Clears the Memory Wrap Error bit in the status register

Driver - HRM_SetRoutingResetRegister

HRM_STATUS WINAPI HRM_SetRoutingResetRegister(HANDLE handle, USHORT rrrData)

handle: HRM-TDC module handle

rrrData: Don't care

MCL, MCH – Memory Count LO/HI Register

Register Description

When the system is commanded to initialize the memory, these registers will define the block size of 32-bit memory locations to be written to with the value defined by the **Load Fill Value** registers. When the system is put into Time-Tag or TCSPC Time-Tag mode, these registers will define the number of 32-bit memory locations to be stored as time-tag data before halting. If these registers are set to 0 the time-tag processor will run until commanded to stop by resetting the state machine.

For further details **see MBR** (Md bits = 000).

Driver - HRM_SetMemoryCountRegister

HRM_STATUS WINAPI HRM_SetMemoryCountRegister(HANDLE handle, ULONG mcrData)

handle: HRM-TDC module handle

mcrData: Number of 32-bit locations to process

FSR – Frequency Select Register

Register Description

The HRM-TDC module provides a programmable frequency output. This register defines the number of 5ns cycles required to complete the HI and LO parts of the cycle. The most significant 8 bits of the FSR defines the HI time and the least significant 8 bits defines the LO time. However, there is an offset of 1 such that:

Setting this value to 0x0000 would result in an output waveform 5ns low followed by 5ns high.

Setting this value to 0x0309 would result in an output waveform 20ns HI, 50ns LO.

When in FIFO Time-Tagging mode, setting the FSR to the value of **0xFFFF** will force the module to operate in **Resync** and the output frequency will be fixed to 250KHz.

Driver - HRM_SetFrequencySelectionRegister

HRM_STATUS WINAPI HRM_SetFrequencySelectionRegister(HANDLE handle,USHORT fsrData)

handle: HRM-TDC module handle

fsrData: Value to write to the FSR

IDR – I/O Direction Register

Register Description

The 16-bit I/O signals of the HRM-TDC can be programmed to be inputs or outputs. The value of this register defines the direction of each I/O bit. Setting a bit in this register to '1' will program the corresponding I/O bit as an output. Setting a bit in this register to '0' will program the corresponding I/O bit as an input.

Driver - HRM_SetIODirectionRegister

HRM_STATUS WINAPI HRM_SetIODirectionRegister(HANDLE handle, USHORT iodrData)

handle: HRM-TDC module handle

iodrData: Value to write to the IDR

IVR – I/O Value Register

Register Description

Writing to this register sets any I/O bit, enabled as an output, to the value of its corresponding bit.

Driver - HRM_SetIOValueRegister

HRM_STATUS WINAPI HRM_SetIOValueRegister(HANDLE handle, USHORT iovrData)

handle: HRM-TDC module handle

iovrData: Value to write to the IVR

BCL, BCH – Bin Count LO/HI Register

Register Description

These registers define the maximum number bins that can occur during the period of the TCSPC clock. This count can be calculated as:

Bin Count = MOD(Clock Period/Resolution) + 1

Resolution = 26.9851ps.

The Bin Count is a 23-bit number. BCL defines the least significant 16 bits and BCH defines the most significant 7 bits. It is **important** that this value is correctly set for both Time-Binning **and** Time-Tagging.

Note: This feature is disabled if bit 6 of the mode register is clear.

Driver - HRM_SetBinCountRegister

HRM_STATUS WINAPI HRM_SetBinCountRegister(HANDLE handle, ULONG bcrData)

handle: HRM-TDC module handle

bcrData: 32-bit value to write to the BCH, BCL registers

UCL, UCH – USB Count HI/LO Register

Register Description

These registers define the number of 32-bit words to be read from the USB high-speed interface.

Driver - HRM_SetUSBCountRegister

HRM_STATUS WINAPI HRM_SetUSBCountRegister(HANDLE handle, ULONG ucrData)

handle: HRM-TDC module handle

ucrData: Number of 32-bit words to be read from the USB high-speed interface

HRS, HRM-TDC Status Register

Register Description

Reading this register will report the status of the HRM-TDC module as follows:

D15	D14	D13	D12	D11	D10	D09	D08	D07	D06	D05	D04	D03	D02	D01	D00
MC	MT2	MT1	MT0	CH1	CH0	RSY	0	0	0	0	OV	ME	FC	HS	TP

TP: If set to '1', the TCSPC time-tag/time-bin processor is active.

HS: If set to '1', the memory high-speed data transfer processor to the USB port will be active.

FC: If set to '1' the FPGA configuration processor is active.

ME: If set to '1' indicates that a TIME-TAG memory WRAP-ROUND error has occurred.

OV: This bit will be cleared when the state machine is reset.

OV will go to '1' if, during processing, the 32-bit 5ns resolution macro timer wraps-round from maximum back to 0.

RSY: If set to '1' the module is set such that, when in FIFO Time-Tagging mode, it will operate in **Resync** (FSR is set to 0xFFFF).

CH: These two bits define the module type 1, 2 or 4 channels.

CH1	CH0	TYPE
0	0	1 Channel
0	1	2 Channel
1	0	3 Channel
1	1	4 Channel

MT: These three bits define the memory card type/size being used:

MT2	MT1	MT0	SIZE
0	0	0	Reserved
0	0	1	Reserved
0	1	0	Reserved
0	1	1	Reserved
1	0	0	32 Mbytes
1	0	1	16 Mbytes
1	1	0	8 Mbytes
1	1	1	No card installed

MC: If set to '1', only one card of MT type is installed. If '0', two cards of MT type are installed.

Driver - HRM_GetStatusRegister

HRM_STATUS WINAPI HRM_GetStatusRegister(HANDLE handle, USHORT *srData)

handle: HRM-TDC module handle

srData: Pointer for saving current 16-bit HRS value

PCR – Product Code Register

Register Description

Reading from this register will report the PRODUCT code. The LS byte will report the product ID and the MS byte defines any variants from the standard product. For a standard HRM-TDC module this value should read 0x0001.

Low Level Driver

HRM_STATUS WINAPI HRM_GetProductCodeRegister(HANDLE handle, USHORT *pcrData)

handle: HRM-TDC module handle

pcrData: Pointer for saving current 16-bit PCR value

SRR – Software Revision Register

Register Description

Reading from this register will report the current rev of the FPGA code.

Low Level Driver

HRM_STATUS WINAPI HRM_GetSoftwareRevisionRegister(HANDLE handle, USHORT *srrData)

handle: HRM-TDC module handle

srrData: Pointer for saving current 16-bit SRR value

MIR – Module ID 1, 2, 3, 4 Register

Register Description

Reading from these four registers will report the contents of the 'on-board' serial ID chip. The contents of the serial ID chip is comprised of 64 bits. The MSB of ID-1 will be the first bit returned from the ID chip. The LSB of ID-4 will be the last bit returned from the ID chip.

Driver - HRM_GetModuleIDRegister

HRM_STATUS WINAPI HRM_GetModuleIDRegister(HANDLE handle, BYTE *midData)

handle: HRM-TDC module handle

midData: Pointer for saving text string of the HRM-TDC module ID

WCH – Write Count HI Register

Register Description

When operating in time-tag mode, this register will contain the number of 1K (1024 bytes) blocks of data that have been written to memory by the time-tag processor. When the time-tag processor is running, this register should be used to track the memory for continuous download of data.

Note: This register automatically wraps around at the maximum address as defined by the memory configuration bits in the status register.

Driver - HRM_GetWriteCountRegister

HRM_STATUS WINAPI HRM_GetWriteCountRegister(HANDLE handle, ULONG *wrrData)

handle: HRM-TDC module handle

wrrData: Pointer for saving current 32-bit value of WCH and WCL registers

WCL – Write Count LO Register

Register Description

When operating in time-tag mode, this register will contain the residual bytes (0-1023 bytes) that have been written to memory by the time-tag processor. The value of the WCH and WCL are not locked. The WCH should be used for tracking the memory data. Once the time-tagging has been stopped the WCL register should be used to download any remaining data.

Driver – HRM_GetWriteCountRegister

See WCH register

Non-Register Specific Low Level Drivers

Driver - HRM_InitMemory

```
HRM_STATUS WINAPI HRM_InitMemory(  HANDLE   handle,
                                   ULONG    addr,
                                   ULONG    len,
                                   ULONG    fillData)
```

Fill a block of memory with a specific bit pattern.

handle: HRM-TDC module handle

addr: 32-bit starting address

len: Number of 32-bit locations to fill

fillData: 32-bit value to fill the memory with

Driver - HRM_ReadMemory

```
HRM_STATUS WINAPI HRM_ReadMemory(  HANDLE   handle,
                                   USHORT   modeMask,
                                   ULONG    addr,
                                   ULONG    len,
                                   BYTE     *buf)
```

Read a block of data from a given location in memory.

handle: HRM-TDC module handle

modeMask: Mask to define desired state of mode register bits when executing the function

addr: 32-bit starting address

len: Number of 32-bit locations to read

buf: Pointer to buffer for storing the data

Driver - HRM_ReadFIFOMemory

```
HRM_STATUS WINAPI HRM_ReadFIFOMemory(  HANDLE   handle,
                                       USHORT   modeMask,
                                       ULONG    addr,
                                       ULONG    len,
                                       BYTE     *buf)
```

Read a block of data from a given location in memory when card is operating in FIFO mode.

handle: HRM-TDC module handle

modeMask: Mask to define desired state of mode register bits when executing the function

addr: 32-bit starting address

len: Number of 32-bit locations to read

buf: Pointer to buffer for storing the data

Driver - HRM_GetMemorySize

HRM_STATUS WINAPI HRM_GetMemorySize(HANDLE handle,
ULONG *size)

Gets the memory size of the module in bytes.

handle: HRM-TDC module handle

size: Pointer to location for storing number of memory bytes.

HIGH LEVEL DLL FUNCTIONS

The HRM-TDC DLL (HRMTimeAPI.DLL) contains a set of high level drivers designed to allow the user to easily stream date from the module to memory or file. These drivers are as follows:

Driver - HRM_StartHistogramFSM

```
HRM_STATUS WINAPI HRM_StartHistogramFSM(HANDLE   handle,
                                        USHORT   tcspc,
                                        USHORT   microlsb)
```

Setup the module in histogram mode and start it running.

handle: HRM-TDC module handle

tcspc: Value 1 for TCSPC histogram mode. Value 0 for multiscalar/averaging mode.

microlsb: Time-bin resolution. 0=27ps, 1=54ps, 2=108ps etc.

HRM_STATUS returned equal to **HRM_OK** if success

Driver - HRM_StreamTCSPC2File

```
HRM_STATUS WINAPI HRM_StreamTCSPC2File( HANDLE   handle,
                                        BYTE*    outfname,
                                        ULONG    recordinglength,
                                        ULONG    esr,
                                        USHORT   microbits,
                                        USHORT   microlsb,
                                        USHORT   macrobits,
                                        USHORT   macrolsb)
```

Stream FIFO date to file (TCSPC with MACRO mode).

handle: HRM-TDC module handle

outfname: File name for storing data

recordinglength: Time in msec to stream data to file

esr: Module ESR register value for defining channels and edge sensitivity

microbits: Number of micro TCSPC measurement bits to use

microlsb: TCSPC resolution. 0=27ps, 1=54ps, 2=108ps etc.

macrobits: Number of MACRO bits to use

macrolsb: MACRO time resolution. 0=5ns, 1=10ns, 2=20ns etc.

HRM_STATUS returned equal to **HRM_OK** if success

Data format

Each time-tag value will be a 32 bit unsigned value.

The 2 LSBs, C1 and C0, will define the channel the time-tag was received on.

C1	C0	Channel
0	0	0
0	1	1
1	0	2
1	1	3

The remaining 30 bits are shared between the MICRO and MACRO bits.

Note:

The total of the MICRO and MACRO bits **must** add up to 30. If this is not true the function will return an error.

Driver - HRM_StreamTCSPC2FMem

HRM_STATUS WINAPI HRM_StreamTCSPC2Mem(

HANDLE	**handle,**
BYTE	***buf,**
ULONG	**bufsize,**
ULONG	**recordinglength,**
ULONG	**esr,**
USHORT	**microbits,**
USHORT	**microlsb,**
USHORT	**macrobits,**
USHORT	**macrolsb,**
ULONG	***recordedbytes)**

Stream FIFO date to memory buffer (TCSPC with MACRO mode).

handle:	HRM-TDC module handle
buf:	Pointer to memory buffer
bufsize:	Memory buffer size in bytes. Recording stops if this is reached.
recordinglength:	Time in msec to stream data to buffer (while buffer not full)
esr:	Module ESR register value for defining channels and edge sensitivity
microbits:	Number of micro TCSPC measurement bits to use
microlsb:	TCSPC resolution. 0=27ps, 1=54ps, 2=108ps etc.
macrobits:	Number of MACRO bits to use
macrolsb:	MACRO time resolution. 0=5ns, 1=10ns, 2=20ns etc.
recordedbytes:	Pointer to location for storing total number of bytes saved to buffer

HRM_STATUS returned equal to **HRM_OK** if success

Data format

See **HRM_StreamTCSPC2File**

Driver - HRM_StreamTimeTags2File

HRM_STATUS WINAPI HRM_StreamTimeTags2File(

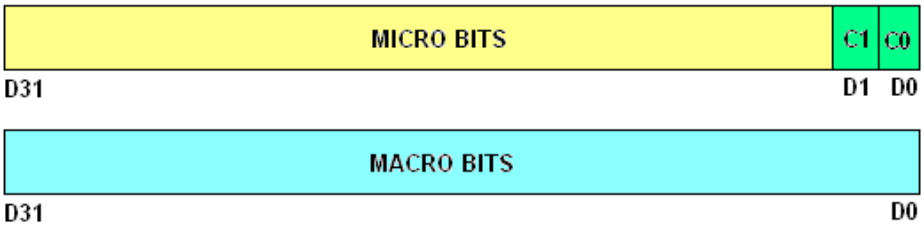
HANDLE	**handle,**
BYTE	***outfname,**
ULONG	**recordinglength,**
ULONG	**esr,**
USHORT	**microlsb)**

Stream FIFO date to file (FIFO Time-Tagging mode).

handle:	HRM-TDC module handle
outfname:	File name for storing data
recordinglength:	Time in msec to stream data to file
esr:	Module ESR register value for defining channels and edge sensitivity
microlsb:	Micro resolution. 0=27ps, 1=54ps, 2=108ps etc.

HRM_STATUS returned equal to **HRM_OK** if success

Data format



Each time-tag consists of two 32-bit unsigned values.

1st word

The 2 LSBs, C1 and C0, will define the channel the time-tag was received on.

C1	C0	Channel
0	0	0
0	1	1
1	0	2
1	1	3

The remaining bits are reserved for the MICRO time.

2nd word

Free Running:

The second word is a free running 32-bit counter with an LSB of 5ns. The MICRO counter is a 23 bit counter with an LSB value of 26.9851ps. This counter rolls over at a value of 0x50FFFF. By comparing the previous MACRO time with the current MACRO time the number of roll overs, if any, of the MICRO counter can be determined. This allows the time-tag values to be resolved indefinately.

For details of the MICRO counter and how this is achieved see article in appendix.

Resync:

The second word is a 40MHz (25ns LSB) counter synchronized to the 250KHz START clock. By comparing the previous MACRO time with the current MACRO time the number of roll overs, if any, of the MICRO counter can be determined. This allows the time-tag values to be resolved indefinately.

For details of the MICRO counter and how this is achieved see article in appendix.

Driver - HRM_StreamTimeTags2Mem

```
HRM_STATUS WINAPI HRM_StreamTimeTags2Mem(   HANDLE    handle,
                                            BYTE      *buf,
                                            ULONG     bufsize,
                                            ULONG     recordinglength,
                                            ULONG     esr,
                                            USHORT    microlsb,
                                            ULONG     *recordedbytes)
```

Stream FIFO date to memory buffer (FIFO Time-Tagging mode).

handle:	HRM-TDC module handle
buf:	Pointer to memory buffer
bufsize:	Memory buffer size in bytes. Recording stops if this is reached.
recordinglength:	Time in msec to stream data to buffer (while buffer not full)
esr:	Module ESR register value for defining channels and edge sensitivity
microlsb:	TCSPC resolution. 0=27ps, 1=54ps, 2=108ps etc.
recordedbytes:	Pointer to location for storing total number of bytes saved to buffer

HRM_STATUS returned equal to **HRM_OK** if success

Data format

See **HRM_StreamTimeTags2File**

Driver - HRM_GetTimeTagGap

HRM_STATUS WINAPI HRM_GetTimeTagGap(**ULONG pMacro,**
ULONG pMicro,
ULONG cMacro,
ULONG cMicro,
BYTE *channel,
double *gap)

Calculates the gap between the previous FIFO time-tag and the current time-tag and saves it in picoseconds. This function is for FREE RUNNING mode only.

pMacro:	32-bit MACRO value of previous time-tag
pMicro:	32-bit MICRO value of previous time-tag
cMacro:	32-bit MACRO value of current time-tag
cMicro:	32-bit MICRO value of current time-tag
channel:	Storage location for channel ID (0, 1, 2 or 3)
gap:	Storage location for calculated gap value in picoseconds

HRM_STATUS returned TRUE if error

Note:

All four input parameters, pMacro, pMicro, cMacro and cMicro, are data values as read directly from a FIFO Time-Tagging **RAW** buffer or file.

Driver - HRM_GetFifoTCSPCinfo

HRM_STATUS WINAPI HRM_GetFifoTCSPCinfo(**ULONG tag,**
ULONG microBits,
ULONG microLSB,
ULONG macroLSB,
BYTE *channel,
double *micro,
double *macro)

Get the channel ID, and the macro and micro times from the FIFO TCSPC 32-bit time-tag.

The macro time is returned in nanoseconds and the micro time is returned in picoseconds.

tag:	32-bit time-tag
microBits:	Number of micro bits in time-tag (0 to 23).
microLSB:	LSB of micro time (0 to 22)
macroLSB:	LSB of micro time (0 to 31)
channel:	Storage location for channel ID (0, 1, 2 or 3)
micro:	Storage location for micro time in picoseconds
macro:	Storage location for macro time in nanoseconds

HRM_STATUS returned equal to **HRM_OK** if success

Driver - HRM_CorrelateTimeBins

HRM_STATUS WINAPI HRM_CorrelateTimeBins(HANDLE handle,
ULONG *x,
ULONG lx,
ULONG *y,
ULONG ly,
ULONG maxlag,
double *corr

Carries out a correlation algorithm on two sets of Time Bins.

handle:	HRM-TDC module handle
x:	Pointer to an array of time bin values
lx:	Number of bins in x array
y:	Pointer to an array of time bin values
ly:	Number of bins in y array
maxlag:	Total number of bins to be used as the lag time
corr:	Pointer to array for storing the correlation results

HRM_STATUS returned equal to **HRM_OK** if success

Note: For autocorrelation the user must input the same set of time bins for **x** and **y**.

For details of the correlation algorithm used see article in appendix.

Driver - HRM_RunFifoTimeTagging

HRM_STATUS WINAPI HRM_RunFifoTimeTagging(HANDLE handle,
USHORT ESRreg,
USHORT microlsb
USHORT mode)

Starts running the FIFO time tagging mode. Once this has been executed the function **HRM_GetFifoData** can be used to continuously download the data.

handle:	HRM-TDC module handle
ESRreg:	Module ESR register value for defining channels and edge sensitivity
microlsb:	Resolution. 0=27ps, 1=54ps, 2=108ps etc.
mode:	1 = FIFO_FREE_RUNNING or 2 = FIFO_RESYNC

HRM_STATUS returned equal to **HRM_OK** if success

Driver - HRM_RunFifoTCSPC

HRM_STATUS WINAPI HRM_RunFifoTCSPC(HANDLE handle,
USHORT ESRreg,
USHORT microbits,
USHORT microlsb,
USHORT macrolsb)

Starts running the FIFO TCSPC mode. Once this has been executed the function **HRM_GetFifoData** can be used to continuously download the data.

handle: HRM-TDC module handle

ESRreg: Module ESR register value for defining channels and edge sensitivity

microbits: Number of micro TCSPC bits in time-tag (max value = 23)

microlsb: TCSPC resolution. 0=27ps, 1=54ps, 2=108ps etc.

macrolsb: Macro time resolution. 0=5ns, 1=10ns, 2=20ns etc.

HRM_STATUS returned equal to **HRM_OK** if success.

Note: Each time tag consists of 1 x 32-bit word. The least significant 2 bits are reserved for the channel ID leaving 30 bits to be shared between the macro and micro time.

Driver - HRM_GetFifoData

HRM_STATUS WINAPI HRM_GetFifoData(HANDLE handle,
USHORT mode,
ULONG max,
ULONG *size,
ULONG *buffer)

Once the module is running in FIFO time tagging or FIFO TCSPC mode (see HRM_RunFifoTimeTagging and HRM_RunFifoTCSPC) this function can be used to continuosly download the data from the FIFO. This function will download all the data available up to a specified max count from the FIFO and save it in the buffer. The actual number of 32-bit values read from the FIFO will be stored in the location pointed at by 'size'. This function keeps a pointer that is updated as data is downloaded from the FIFO. Hence, consecutive calls to this function will read the data in sequence as it is stored in the FIFO. This function allows the user to continuosly download the FIFO data in blocks allowing processing of the data between each call.

Note:

- The data transferred will be rounded to a number of 256 x 32-bit elements. Therefore the minimum data transfer is 256 x 32-bit elements. The minimum allowable value of **max** is 256.
- The amount of processing time available between each call is dependant on the hit rate at the module input(s).

handle: HRM-TDC module handle

mode: 1 = FIFO_TIMETAGGING or 2 = FIFO_TCSPC

max: Maximum elements to store

size: Pointer to location for storing actual number of elements read from the FIFO

buffer: Pointer to 32-bit buffer for storing the data

HRM_STATUS returned equal to **HRM_OK** if success

Driver - HRM_ConvertRAWtoCSV

HRM_STATUS WINAPI HRM_ConvertRAWtoCSV(USHORT mode,
USHORT mocroBits,
BYTE *rawFile,
BYTE *csvFile)

Converts a previously generated RAW binary file into a CSV file for importing into a spreadsheet or TEXT editor.

mode:	FIFO_TCSPC, FIFO_FREE_RUNNING or FIFO_RESYNC
microBits:	Number of micro bits. Only applicable for FIFO_TCSPC mode.
rawFile:	Name of RAW binary file
csvFile:	Name of file to store TEXT formatted data

HRM_STATUS returned equal to **HRM_OK** if success

DLL ERROR REPORTING

All DLL functions return TRUE on error and FALSE on success. When a DLL function encounters an error it also updates a global ERROR word describing the reason for the error. This error can be inspected at any time by calling the function **HRM_GetLastError( ).**

Driver - HRM_GetLastError

HRM_STATUS WINAPI HRM_GetLastError(HRM_STATUS newVal)

This function returns the last error that was encountered by the DLL functions.

newVal: Value to update the ERROR word with after returning the current value.

Note:

For normal operation the value of newVal should be set to one of two values:

0	HRM_OK	: Clear error after reading value
9999	HRM_NO_CHANGE	: Do not change error value

The possible values returned by this function are as follows:

0	HRM_OK	:No error
1	HRM_ERROR	:Function error
2	HRM_NO_LICENSE	:License error
3	HRM_OPEN_USB	:Could not open USB module
4	HRM_CLOSE_USB	:Could not close USB module
5	HRM_INV_HANDLE	:Invalid HANDLE
6	HRM_RAW_FILE	:Could not open RAW file
7	HRM_OUTPUT_FILE	:Could not open O/P file
8	HRM_INV_PARAMETER	:Invalid function parameter
9	HRM_WRITE_COMMAND	:Error writing command
10	HRM_READ_COMMAND	:Error reading command
11	HRM_READ_DATA	:Error reading data block
12	HRM_FIFO_OVERFLOW	:FIFO has overflowed
13	HRM_BUFFER_FULL	:Memory buffer full
14	HRM_TIMEOUT	:Timeout error
15	HRM_NO_MODULE_FOUND	:Could not detect module

DLL APPLICATION EXAMPLES

Streaming Time-Tags to file

Description

The following example streams Time-Tags to a binary file and then creates a TEXT file from the RAW binary file. If there is no additional argument (argc = 1) then streaming will be carried out in FIFO Time-Tagging mode. If there is an additional argument (argc > 1) then streaming will be carried out in FIFO TCSPC with MACRO time mode.

Source Code

```
#include <stdio.h>
#include <stdlib.h>
#include <windows.h>
#include "HRM-TDCAPI.h"

typedef unsigned char    Ubyte;     /* Unsigned byte    */
typedef char             Sbyte;     /* Signed byte      */
typedef unsigned short   Uword;     /* Unsigned 16 bits */
typedef short            Sword;     /* Signed 16 bits   */
typedef unsigned int     Ulong;     /* Unsigned 32 bits */
typedef int              Slong;     /* Signed 32 bits   */
typedef double           Sdoub;     /* Double           */

void main(Sword argc, Sbyte *argv[])
{
HANDLE        hdl[10];
HRM_STATUS    error;
FILE          *fi, *fo;
Sbyte         ch;
Sword         i, flag;
Ulong         moduleCount, ttag[2], pMAC, pMIC, cMAC, cMIC, Num;
Sdoub         gapT, Tot, mac, mic;

    error = HRM_OK;
    pMAC  = 0;
  pMIC  = 0;
  fi    = NULL;
  fo    = NULL;

  /*
   Detect the number of HRM-TDC modules
  */
  HRM_RefreshConnectedModuleList();
  moduleCount = HRM_GetConnectedModuleCount();
```

```
/*
 If a module is present connect to the first module.
 If no module set error and reason in last error report.
*/
if(moduleCount)
    HRM_GetConnectedModuleList(hdl);
else
{
    HRM_GetLastError(HRM_OPEN_USB);
    error = HRM_ERROR;
}

/*
 If no argument do FIFO Time_tagging for 1ms on channel 0.
 If an argument then do FIFO TCSPC with macro time.
  */
if(error == HRM_OK && argc == 1)
    error = HRM_StreamTimeTags2File(hdl[0],"FIFO.RAW",1,0x0009, 0);
else
if(error == HRM_OK)
    error = HRM_StreamTCSPC2File(hdl[0],"FIFO.RAW",1,0x0009,13,0,17,0);

  /*
 Open the RAW file and create a TXT file
*/
if(error == HRM_OK)
{
    fi = fopen("FIFO.RAW", "r+b");
    fo = fopen("FIFO.TXT", "w+t");
}

/*
 If file open error, set error and reason in last error report.
*/
if(error == HRM_OK && (fi == NULL || fo == NULL))
{
    HRM_GetLastError(HRM_OUTPUT_FILE);
    error = HRM_ERROR;
}

/*
 If an argument then read the TCSPC time-tags, get the macro and
 micro values in ns and ps and put to the TXT file
*/
for(Num=1, flag=1; flag && error == HRM_OK && argc != 1; Num++)
{
    if((fread(ttag, 4, 1, fi)) == 0)
        flag = 0;
```

```
        else
        {
            HRM_GetFifoTCSPCinfo(ttag[0], 13, 0, 0, &ch, &mic, &mac);
            fprintf(fo, "%ld\t%d\t%.0f\t\t%.0f\n", Num, ch, mac, mic);
        }
    }
    /*
     If no argument then read the FIFO time-tags, convert them into ps gap
     times and and put to the TXT file
    */
    for(Num=1, Tot=0, flag=1; flag && error == HRM_OK && argc == 1; Num++)
    {
        if((fread(ttag, 4, 2, fi)) == 0)
            flag = 0;
        else
        {
            cMAC = ttag[1];
            cMIC = ttag[0];
            HRM_GetTimeTagGap(pMAC, pMIC, cMAC, cMIC, &ch, &gapT);
            Tot = (gapT + Tot);
            fprintf(fo, "%ld\t%.0f\t%.0f\n", Num, Tot, gapT);
            pMAC = cMAC;
            pMIC = cMIC;
        }
    }
    /*
     Close the files and report any error
      */
    if(fi != NULL)
        fclose(fi);
    if(fo != NULL)
        fclose(fo);

      if(error == HRM_OK)
          printf("Done");
      else
      {
          error = HRM_GetLastError(HRM_OK);
          printf("Failed: Error code = %d", error);
      }
}
```

Histogram Example

Description

The following example sets up the module in TCSPC or Multi-scalar Histogram mode. This console-based application allows input parameters to define setup information as follows:

Histogram.exe <tcspc> <channels> <time> <clock_period>

<tcspc>	A single char 1 or 0. 1 = tcspc mode, 0 = multi-scalar mode
<channels>	4 chars of value 1 or 0 defining if channel is enabled or disabled
	0001 = Channel 0 only, 1000 = Channel 3 only, 1111 = All channels enabled
<time>	Time in msec to run the histogram mode
<clock_period>	Period of programmable clock in ns.
	This value should be set to a value divisible by 10

Example:

Histogram.exe 1 0101 2000 1000

TCSPC mode, channels 2 and 0 enabled, run for 2 seconds, frequency = 1MHz

0	0	28	0
0	0	95	0
0	0	682	0
0	0	2331	0
0	0	18012	0
0	0	56636	0
0	0	155322	0
0	0	192859	0
0	0	215638	0
0	0	183546	0
0	0	102350	0
0	0	55513	0
0	0	11731	0
0	0	840	0
0	0	152	0
0	0	47	0
0	0	5	0
7	0	0	0
1157	0	0	0
3293	0	0	0
8043	0	0	0
16945	0	0	0
70968	0	1	0
180937	0	0	0
223518	0	0	0
198661	0	0	0
114961	0	0	0
28312	0	0	0
7344	0	0	0
1185	0	0	0
309	0	0	0
99	0	0	0
2	0	0	0

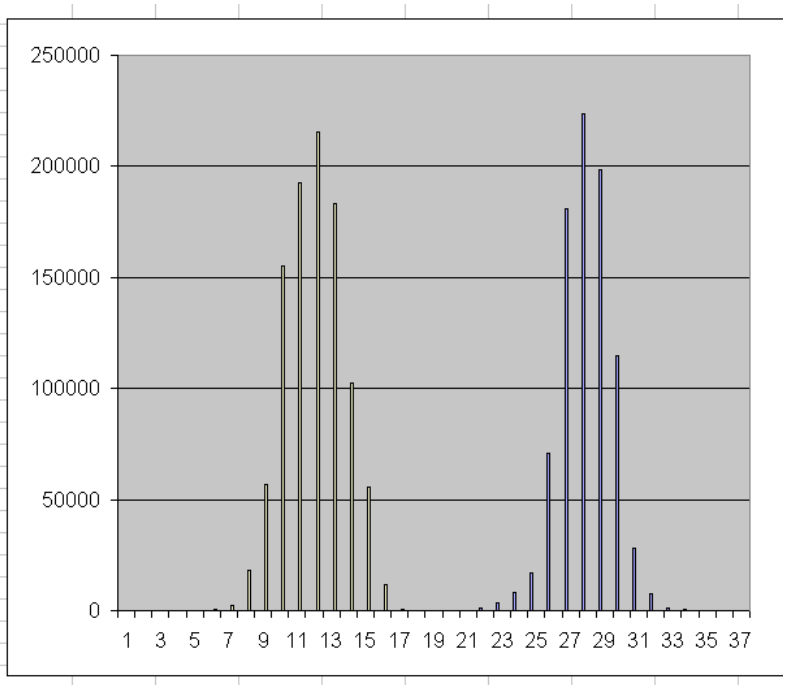


Figure 18

This program assumes that the programmable clock output is connected to all START and STOP inputs of all channels.

The time-bin size, as set in the mode bits register, is set to 32 bits. For this example assume that there is 8Mbytes of memory formatted as 2 Mbytes of 32-bit time-bins.

The function **HRM_StartHistogramFSM( )** uses the AAR register to route the channel ID bits to the most significant address lines. This automatically splits the memory into 4 blocks, 1 for each channel. The histogram for channel 0 will start at 32-word address 0. The histogram for channel 1 will start at 32-word address 0x80000. The histogram

for channel 2 will start at 32-word address 0x100000. The histogram for channel 3 will start at 32-word address 0x180000. The resolution of the timing is fixed at 27ps per bin.

The edge sensitivity register sets an enabled channel to START on the LO-HI edge of the clock and STOP on the HI-LO edge. After the histogram is run for **<time>** milliseconds the histogram is stopped and all the memory is read to a buffer. This program then uses the clock period to calculate the address of the time-bins corresponding to ~20ns before the STOP (HI-LO transition of the clock). It then reads to file a range of time-bins that finishes ~20ns after the STOP. This is done to save the time-bins where the histogram resides whilst keeping the file size to a minimum. As the STOP signals are from a clock the resulting histogram will be a narrow peak. The width of this peak will represent the amount of noise/jitter on the clock.

The screen shot shows a section of the output file **(Histogram.csv)** using EXCEL. The right hand side shows the 4 columns of time-tag values. The graph is a simple EXCEL representation of this data.

Source Code

```
#include <stdio.h>
#include <stdlib.h>
#include <windows.h>
#include "HRM-TDCAPI.h"

typedef unsigned char    Ubyte;     /* Unsigned byte     */
typedef char             Sbyte;     /* Signed byte       */
typedef unsigned short   Uword;     /* Unsigned 16 bits  */
typedef short            Sword;     /* Signed 16 bits    */
typedef unsigned int     Ulong;     /* Unsigned 32 bits  */
typedef int              Slong;     /* Signed 32 bits    */
typedef double           Sdoub;     /* Double            */

#define CH0_ADDR     0
#define CH1_ADDR     CH0_ADDR+0x80000
#define CH2_ADDR     CH1_ADDR+0x80000
#define CH3_ADDR     CH2_ADDR+0x80000

Ulong buffer [0x200000];

void main(Sword argc, Sbyte *argv[])
{
HRM_STATUS    error;
Uword    tcspc, delay, chann;
Uword         period, clock;
Ulong         moduleCount, offset, range, i;
HANDLE        hdl[10];
FILE          *fl;

    /*
     Initialise variables and clear error report
    */
    error  = HRM_OK;
    tcspc  = 0;
```

```
  delay  = 0;
  chann  = 0;
  period = 2000;
  fl     = NULL;
  HRM_GetLastError(HRM_OK);

  /*
   Set error if too few input parameters and set reason in last error.
  */
  if(argc < 4)
{
    HRM_GetLastError(HRM_INV_PARAMETER);
    error = HRM_ERROR;
}

  /*
   If define frequency then read period in ns and ensure
   not greater than maximum allowable value of 2500.
  */
  if(argc > 4)
      period = (Uword)atoi(argv[4]);
  if(period > 2500)
      period = 2500;

  /*
   Read from ~20ns before 1/2 cycle to ~20ns after.
   Form the offset in the memory where reading is to start.
   This is ~ 20ns before half period of clock. Then set the
   range for reading results of 40ns.
  */
  clock = (Uword)(period / 2);
  i = (Ulong)clock;
  if (i >= 20)
      i = (Ulong)(i - 20);
  offset = (Ulong)(i  * 1000 / 27);
  range  = (Ulong)(40 * 1000 / 27);

  /*
   Form the programmable clock value. Upper byte and lower byte
are set to 1/2 period in 5ns per bit - 1.

*/
clock = (Uword)(clock / 5);
if(clock)
    clock--;
clock = (Uword)((clock << 8) | clock);
/*
 1. Set the flag for TCSPC or MULTI-SCALAR mode
 2. Read in the time in ms for running the histogram.
 3. Form the 4 channel edge enables based on the input parameter.
```

```
    */
    if(error == HRM_OK)
    {
        tcspc = (Uword)(argv[1][0] & 1);
        delay = (Sword)atoi(argv[3]);
        if(argv[2][0] == '1')
            chann |= 0x9000;
        if(argv[2][1] == '1')
            chann |= 0x0900;
        if(argv[2][2] == '1')
            chann |= 0x0090;
        if(argv[2][3] == '1')
            chann |= 0x0009;
    }
     /*
      Detect the number of HRM-TDC modules
     */
     if(error == HRM_OK)
     {
         HRM_RefreshConnectedModuleList();
         moduleCount = (Ulong)HRM_GetConnectedModuleCount();
     }

   /*
    If a module is present connect to the first module.
 If no module, set error and reason in last error report.
  */
  if(error == HRM_OK)
{
    if(moduleCount)
          HRM_GetConnectedModuleList(hdl);
      else
      {
          HRM_GetLastError(HRM_OPEN_USB);
          error = HRM_ERROR;
      }
    }

     /*
      Set the clock frequency.
     */
     if(error == HRM_OK)
         error = HRM_SetFrequencySelectionRegister(hdl[0], clock);

     /*
      Set the channel edge enables.
     */
     if(error == HRM_OK)
         error = HRM_SetEdgeSensitivityRegister(hdl[0], chann);
```

```
/*
 Clear the memory.
*/
if(error == HRM_OK)
    error = HRM_InitMemory(hdl[0], 0, 0x200000, 0);
/*
 Start the histogram running.
*/
if(error == HRM_OK)
    error = HRM_StartHistogramFSM(hdl[0], tcspc, 0);
/*
 Run the histogram for the programmed time in ms.
*/
if(error == HRM_OK)
    for(i = GetTickCount(); (Uword)(GetTickCount() - i) < delay;);

/*
 Stop the histogram process.
*/
if(error == HRM_OK)
    error = HRM_SetModeBitsRegister(hdl[0], 0x0030);

/*
 Read all the memory into the buffer.
*/
if(error == HRM_OK)
    error = HRM_ReadMemory(hdl[0], 0x0030, 0, 0x200000, buffer);

/*
 Open the file and set the headings.
*/
if(error == HRM_OK)
{
    fl = fopen("HISTOGRAM.csv", "w+t");
    fprintf(fl, "Chan 0,Chan 1,Chan 2,Chan 3\n");
}

/*
 For each channel read all the time-bins from 20ns before to 20ns
 after the 1/2 clock cycle and save then in the file.
*/
for(i=0; i!=range && error == HRM_OK; i++)
{
    fprintf(fl, "%ld,%ld,%ld,%ld\n",
            buffer[i+CH0_ADDR+offset], buffer[i+CH1_ADDR+offset],
            buffer[i+CH2_ADDR+offset], buffer[i+CH3_ADDR+offset]);
}
/*
```

```
        Close the file and print error code if failed.
       */
       if(fl)
           fclose(fl);

       if(error == HRM_OK)
           printf("Done");
       else
       {
           error = HRM_GetLastError(HRM_OK);
           printf("Failed: Error code = %d", error);
       }
   }
```

RESOLVING FREE RUNNING FIFO TIME-TAG VALUES

Free Running Algorithm Explained

When the module operates in **Free Running** FIFO Time-Tagging mode, resolving the time-tag values can be quite complicated. A FIFO time-tag consists of two 32-bit unsigned values. The first word reports the MICRO time and channel number. The second word, called the MACRO time, is a 32 bit free running counter value with an LSB of 5ns.

The MICRO counter is a 23 bit counter with an LSB value of 26.9851ps. This counter rolls over at a value of 0x50FFFF. The time for a complete rollover of the MACRO counter is ~21.5 seconds. So, assuming that the intervals between consecutive time-tags is not greater than ~21.5 seconds each time-tag interval can be calculated as follows:

1. Calculate MACRO change dMACRO

If previous MACRO value is less than current MACRO value then

dMACRO = cMACRO – pMACRO

If previous value (pMACRO) is greater than current (cMACRO) then counter has rolled over so

dMACRO = 0x100000000 – pMACRO + cMACRO

2. Calculate complete MICRO rollover time rMICRO

Complete rollover time for MICRO:

rMICRO = 0x510000 * 26.9851ps = 143248136.6016ps

3. Calculate number of complete MICRO rollovers nMICRO

nMICRO = (dMACRO x 5000) / rMICRO (x 5000 to convert dMACRO into ps)

4. Calculate change in MICRO counter dMICRO

If previous value (pMICRO) is less than current value (cMICRO) then

dMICRO = cMICRO – pMICRO

If previous value (pMICRO) is greater than current (cMACRO) then counter has rolled over so

dMICRO = 0x510000 – pMICRO + cMICRO

5. Calculate total time between time-tags dTIME

dTIME = (nMICRO x rMICRO) + (dMICRO x 26.9851) ps

Software Implementation in 'C'

```
int     iMACRO;
double  pMICRO, cMICRO, pMACRO, cMACRO;
double  rMICRO, dMICRO, dMACRO, dTIME;
•
•
•
/*
 Remove channel ID bits from MICRO values and
 Convert to doubles.
*/
pMACRO = (double)PreviousMacroValue;
pMICRO = (double)(PreviousMicroValue >> 2);
cMACRO = (double)CurrentMacroValue;
cMICRO = (double)(CurrentMicroValue >> 2);
/*
 Calculate the MICRO counter rollover time
*/
rMICRO = 0x510000 * 26.9851;

/*
 Calculate the number of MICRO counter rollovers
*/
if(cMACRO >= pMACRO)
    dMACRO = (cMACRO - pMACRO) * 5000.0 / rMICRO;
else
    dMACRO = (cMACRO + 0xFFFFFFFF – pMACRO + 1) * 5000.0 / rMICRO;

/*
 Cast rollover count to get dMACRO as a whole number then
 convert count into picoseconds.
*/
iMACRO = (int)dMACRO;
dMACRO = (double)iMACRO;
dMACRO = dMACRO * rMICRO;

/*
 Calculate the change in MICRO counter in picoseconds
*/
if(cMICRO > pMICRO)
    dMICRO = (cMICRO - pMICRO) * 26.9851;
else
    dMICRO = (cMICRO + 0x510000 – pMICRO) * 26.9851;
/*
 Calculate the change in time from previous to current time-tag
*/
dTIME = dMICRO + dMACRO;
```

RESOLVING RESYNC FIFO TIME-TAG VALUES

Resync Algorithm Explained

When the module operates in **Resync** FIFO Time-Tagging mode, resolving the time-tag values can be quite complicated. A FIFO time-tag consists of two 32-bit unsigned values. The first word reports the MICRO time and channel number. The second word, called the MACRO time, is a 32 bit counter value with an LSB of 25ns that is synchronized to the 250KHz START clock.

The MICRO counter has an LSB value of 26.9851ps. This counter is reset to 0 on every cycle of the 250KHz START clock. So each time-tag value can be calculated as follows:

1. Calculate offset between MACRO and MICRO timers

The first time tag is used to calculate the MACRO offset 'MACoffset' as follows:

MACROoffset = FirstMACRO – ((FirstMICRO * 26.9851) / 25000) (25000ps = 25ns)

The gives the count of the MACRO when the first 4us (250KHz) frame started.

2. Calculate the current 4μs frame

FrameNo = (MACRO – MACROoffset) / 160 (160 x 25ns = 4us – 250KHz)

3. Calculate the remainder of MACRO counts

Remainder = REM of (MACRO – MACROoffset) / 160

4. Now adjust the FrameNo based on possible boundary conditions

If (Remainder < 60 and MICRO > 100000)
    FrameNo = FrameNo – 1;

If MACRO is just past boundary and MICRO is large then Rollover hasn't occurred yet.

If (Remainder > 110 and MICRO < 40000)
    FrameNo = FrameNo + 1;

If MACRO is near end of boundary and MACRO is small the ROLLOVER has already occurred.

5. Now calculate the time in picoseconds

Time = (FrameNo x 4000000) + (MICRO x 26.9851)

Software Implementation in 'C'

```
long    MACOFF, MACRO, MICRO, FRACT;
double  dv1, dv2, dTIME;

/*
 Calculate the MACRO offset count.
*/
dv1    = (double)(FirstMicroValue >> 2);
dv1    = (double)(dv1 * 26.9851);
dv1    = (double)(dv1 / 25000.0);
MACOFF = (long)dv1;
MACOFF = (long)(FirstMacroValue – MACOFF);

•
•
•

/*
 Remove offset and calculate the MACRO and the fraction of frame.
*/
dv1    = (double)(MacroValue – MACOFF);
dv1   /= 160.0;
MACRO  = (long)dv1;
dv2    = floor(dv1);
dv2    = (double)(dv1 - dv2);
dv2    = (double)(dv2 * 160.0);
FRACT  = (long)dv2;

/*
 Increment or decrement the MACRO based on boundary positions.
 If MACRO is just past boundary and MICRO is large then ROLLOVER
 hasn't occurred yet. If MACRO is near end of boundary and MACRO
 is small the ROLLOVER has already occurred.
*/
MICRO = MicroValue >> 2;
if(FRACT < 60 && MicroValue > 100000)
    MACRO--;
if(FRACT > 110 && MicroValue < 40000)
    MACRO++;

/*
 Calculate the time in picoseconds.
*/
dv1   = (double)MACRO;
dv2   = (double)MicroValue;
dTIME = (dv1 * 4000000) + (dv2 * 26.9851);
```

CORRELATION FUNCTION ALGORITHM

In **correlation** mode the system will carry out a single sweep of software bins with all the bins initially set to 0. On completion the system will calculate the correlation between two inputs (cross correlation) or correlation on a single input (auto correlation) and save the result. The number of time-bins to be used for the calculation and the resolution of the bin is programmable. The results will comprise of a number of values equal to the number of time-bins used for the calculation. The position of each value represents the level of phase shift between the input streams. The first value corresponds to a shift of 0, the second a shift of 'T' etc, where 'T' is the resolution of the time-bin. The value of each result represents the level of correlation at that particular phase.

Cross/ Auto correlation is a standard method of estimating the degree to which two series are correlated. Consider two series x(i) and y(i) where i=0,1,2...N-1. The cross correlation r at delay d is defined as

$$r = \frac{\sum_i [(x(i) - mx) * (y(i-d) - my)]}{\sqrt{\sum_i (x(i) - mx)^2} \sqrt{\sum_i (y(i-d) - my)^2}}$$

Where mx and my are the means of the corresponding series. If the above is computed for all delays d=0,1,2,...N-1 then it results in a cross correlation series of twice the length as the original series.

$$r(d) = \frac{\sum_i [(x(i) - mx) * (y(i-d) - my)]}{\sqrt{\sum_i (x(i) - mx)^2} \sqrt{\sum_i (y(i-d) - my)^2}}$$

There is the issue of what to do when the index into the series is less than 0 or greater than or equal to the number of points. (i-d < 0 or i-d >= N) The most common approaches are to either ignore these points or assuming the series x and y are zero for i < 0 and i >= N. In many signal processing applications the series is assumed to be circular in which case the out of range indexes are "wrapped" back within range, ie: x(-1) = x(N-1), x(N+5) = x(5) etc

The range of delays d and thus the length of the cross correlation series can be less than N, for example the aim may be to test correlation at short delays only. The denominator in the expression above serves to normalize the correlation coefficients such that -1 <= r(d) <= 1, the bounds indicating maximum correlation and 0 indicating no correlation. A high negative correlation indicates a high correlation but of the inverse of one of the series.

LABVIEW DRIVER DETAILS

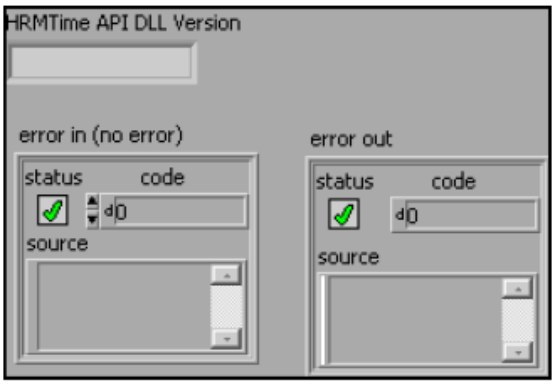
The HRM-TDC Labview driver has been designed to allow the construction of a wide variety of custom applications based on the HRM-TDC module. The library contains VI wrappers for all functions defined in the HRM-TDC API DLL. The following naming convention has been used: the VI wrapper for HRM-TDC API DLL function HRM_XXXX is HRM_XXXX.vi.

For LabVIEW the user must use the modified version of the DLL providid called HRMTimeALI_LV.DLL
In both cases a copy of the relevant DLL MUST reside in the same folder as the application.

HRM-TDC LabView Driver VI List

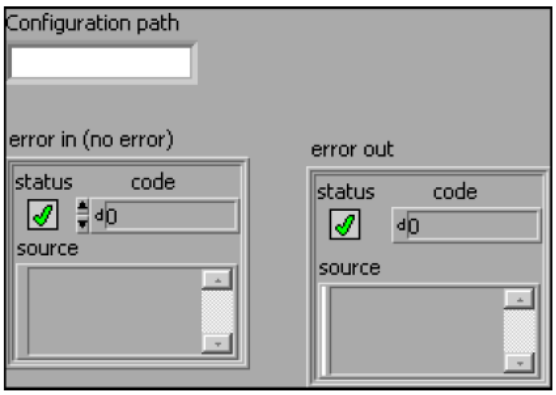
HRM_GetDLLVersion.vi

HRMTime API DLL Version Returns the HRMTime API DLL version

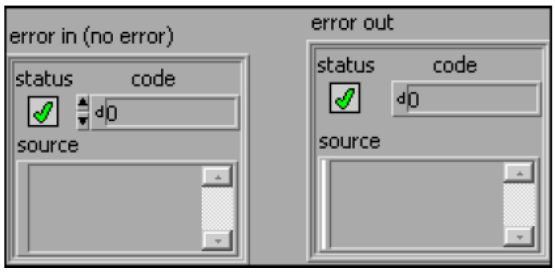


HRM_SetConfigurationPath.vi

Configuration path Path to the folder where the HRMTime feature files are located

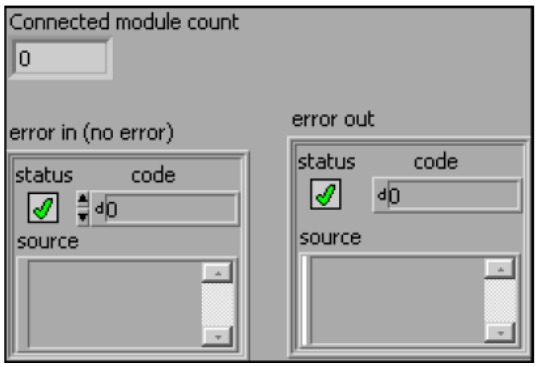


HRM_RefreshConnectedModuleList.vi



HRM_GetConnectedModuleCount.vi

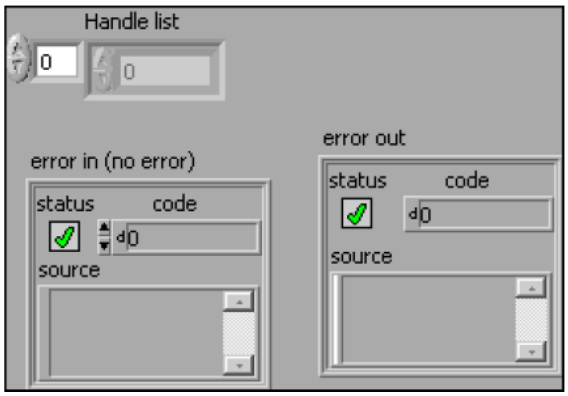
Connected module count Returns the number of connected modules detected by the previous **HRM_RefreshConnectedModuleList** call



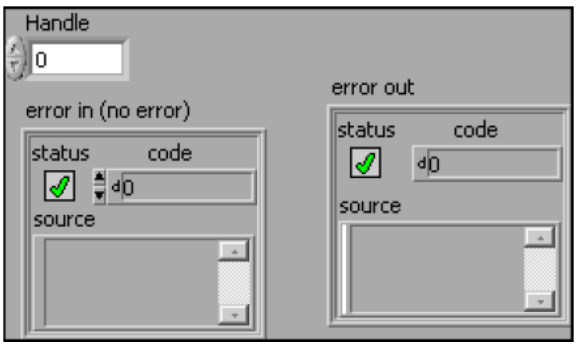
HRM_GetConnectedModuleList.vi

Handle list

Numeric Holds the list of handles for the connected moduled detected by the previous **HRM_RefreshConnectedModuleList** call

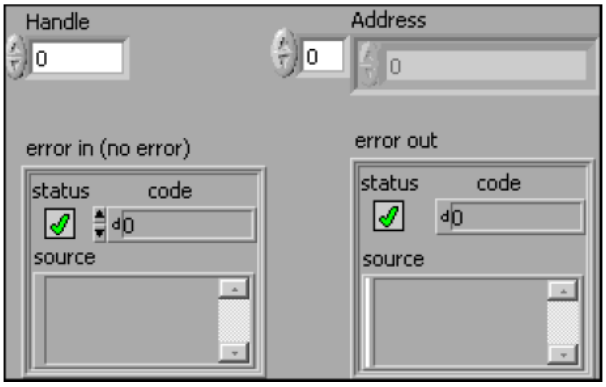


HRM_CloseModule.vi



Handle The module handle

HRM_SetAddressRouteRegister.vi

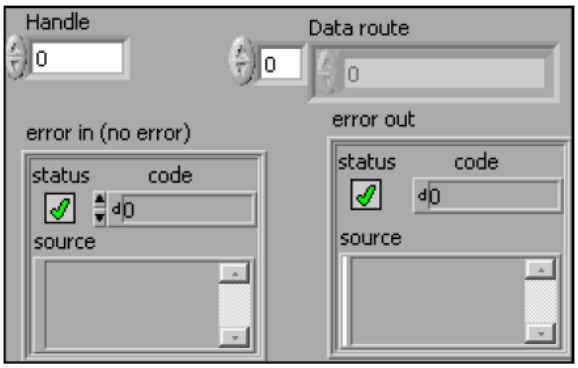


Address routing data

Numeric Data to be written to the address route register

Handle Module handle

HRM_SetDataRouteRegister.vi

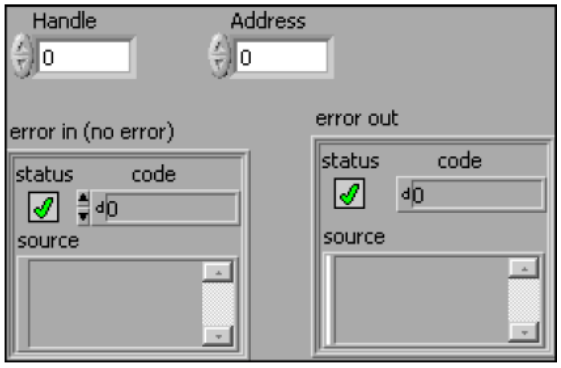


Handle Module handle

Data route routing data

Numeric Data to be written to the Data Route Register

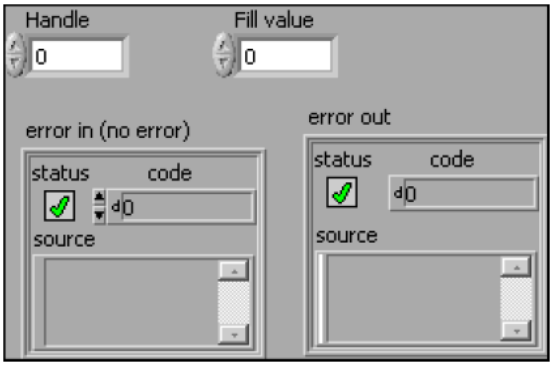
HRM_SetAddressRegister.vi



Address Data to be written to the Address Register

Handle Module handle

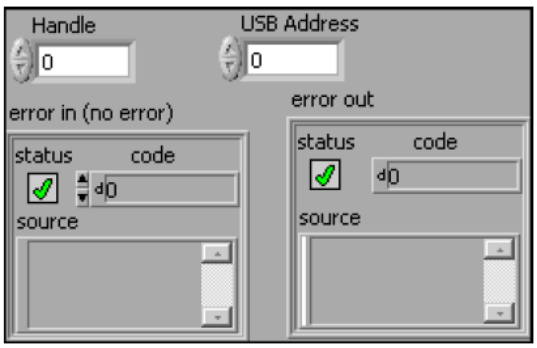
HRM_SetFillValueRegister.vi



Handle Module handle

Fill value Memory fill value

HRM_SetUSBAddressRegister.vi



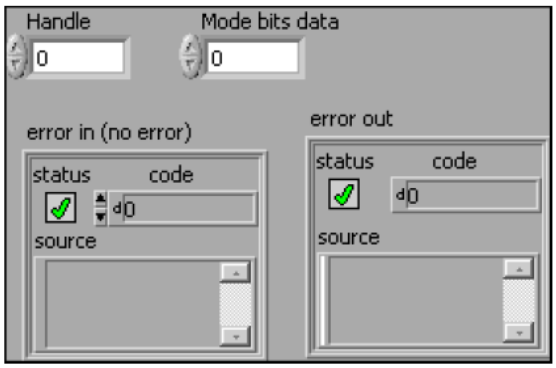
Handle Module handle

USB Address USB block transfer address

HRM_SetModeBitsRegister.vi

Handle Module handle

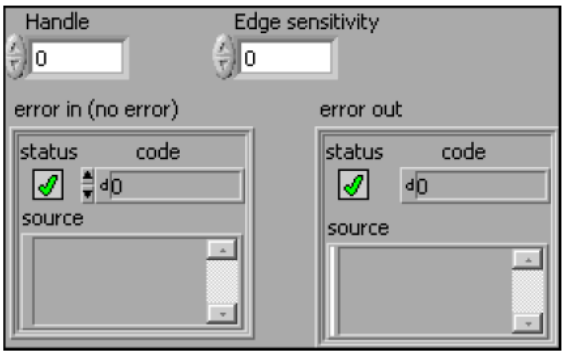
Mode bits data Mode bits data



HRM_SetEdgeSensitivityRegister.vi

Handle Module handle

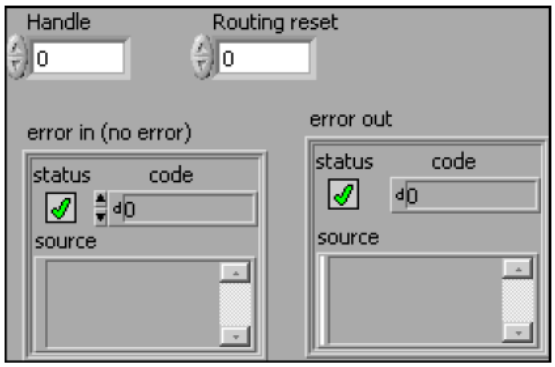
Edge sensitivity Edge sensitivity data



HRM_SetRoutingResetRegister.vi

Handle Module handle

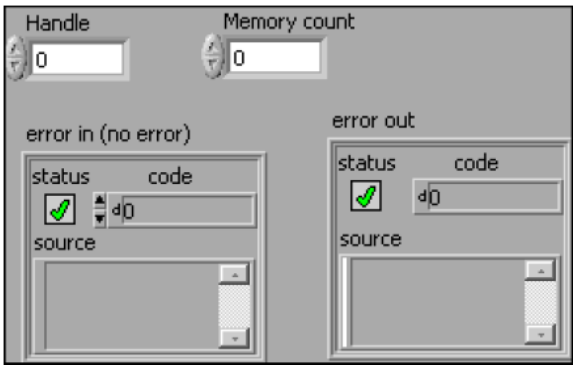
Routing reset Routing reset data



HRM_SetMemoryCountRegister.vi

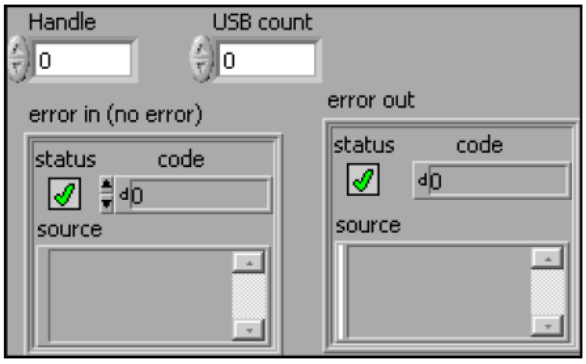
Handle Module handle

Memory count Memory count



HRM_SetUSBCountRegister.vi

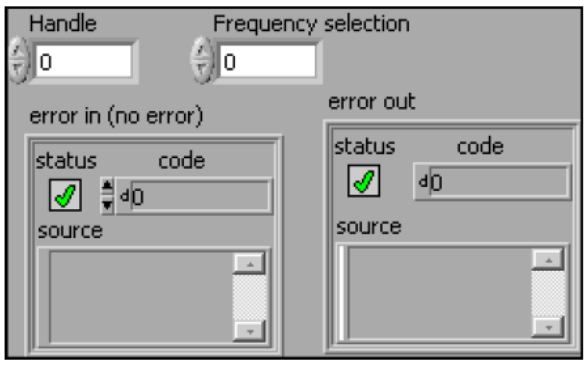
Handle Module handle
USB count USB count data



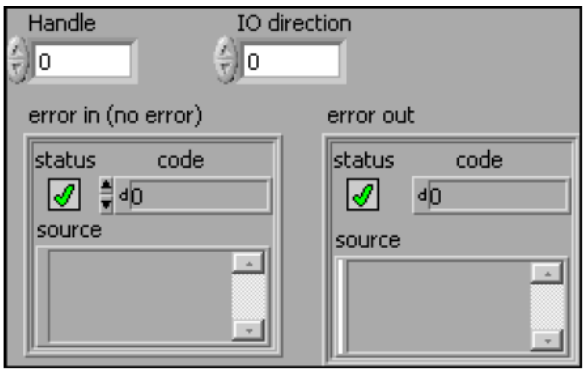
HRM_SetFrequencySelectionRegister.vi

Handle Module handle

Frequency selection Frequency selection data



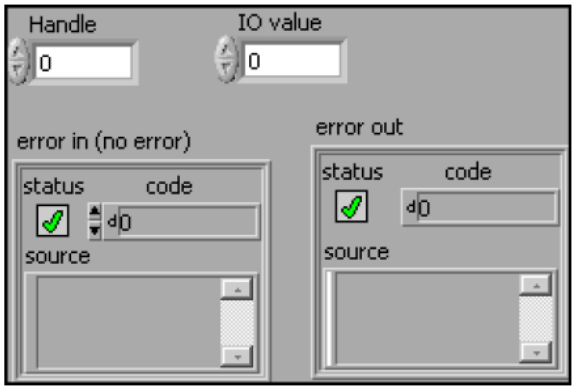
HRM_SetIODirectionRegister.vi



Handle Module handle

IO direction GPIO direction data

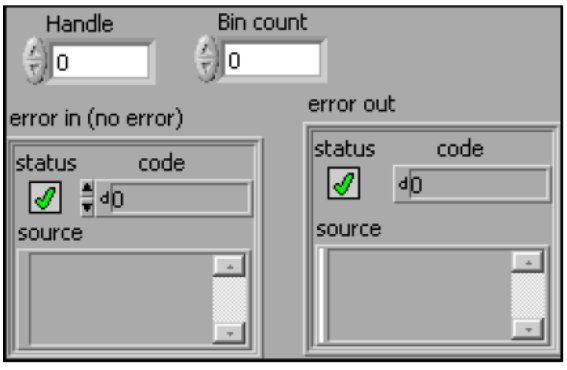
HRM_SetIOValueRegister.vi



Handle Module handle

IO value IO value data

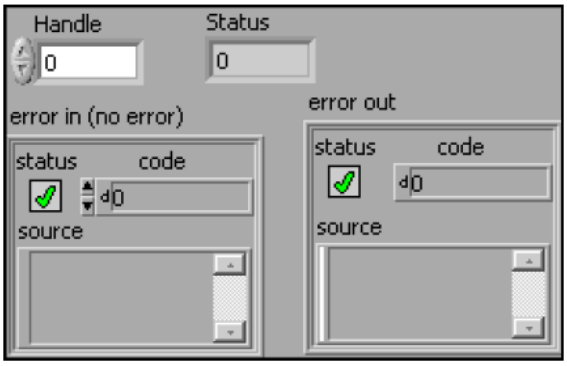
HRM_SetBinCountRegister.vi



Handle Module handle

Bin Count Bin Count

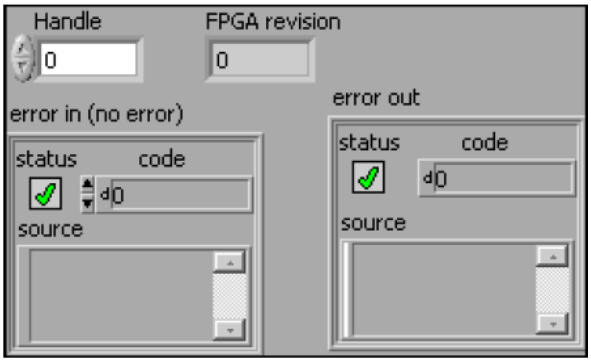
HRM_GetStatusRegister.vi



Handle Module handle

Status Status data

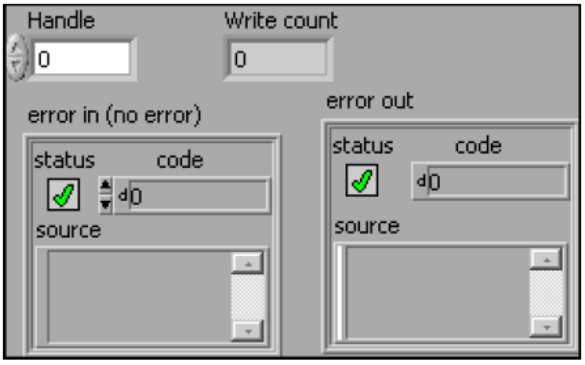
HRM_GetSoftwareRevisionRegister.vi



Handle Module handle

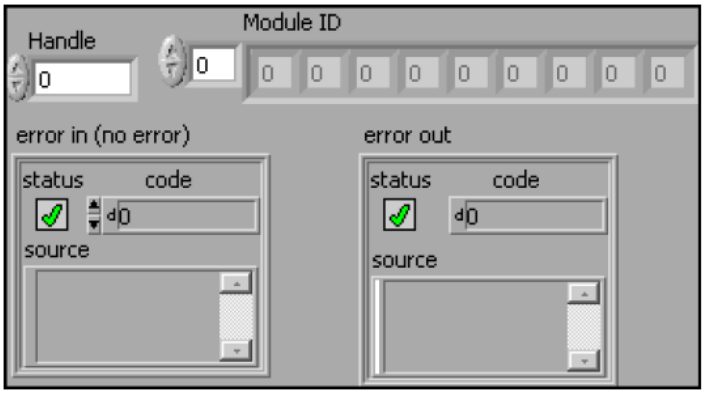
FPGA revision FPGA revision

HRM_GetWriteCountRegister.vi



Handle Module handle
Write count Write count

HRM_GetModuleIDRegister.vi

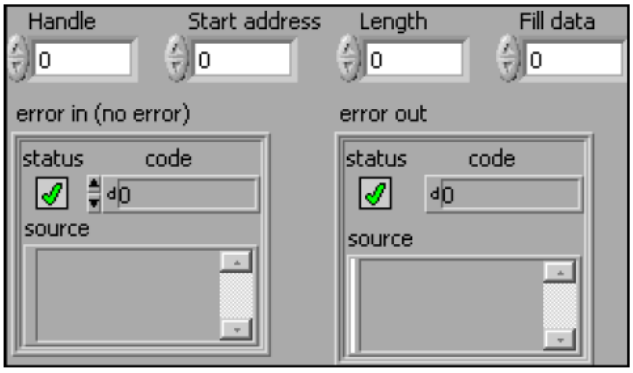


Handle Module handle

Module ID

Numeric Module serial number

HRM_InitMemory.vi



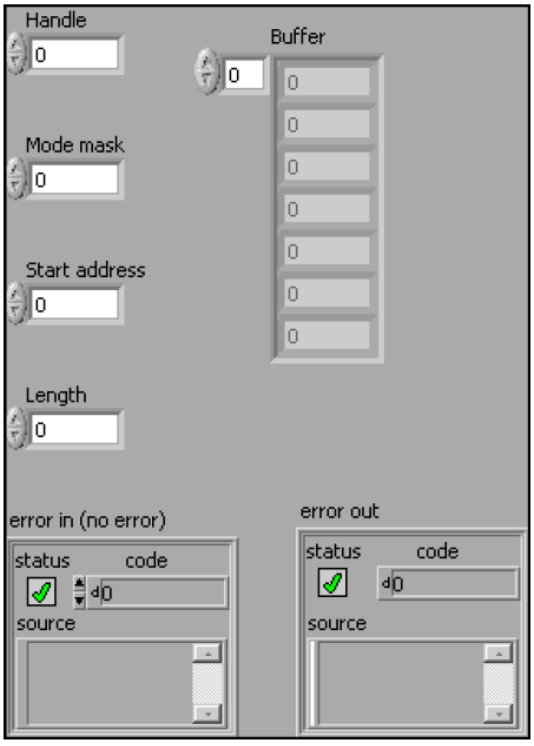
Handle Module handle

Start address Start address

Length Block length

Fill data Fill data

HRM_ReadMemory.vi



Handle Module handle

Mode mask Mode bits mask

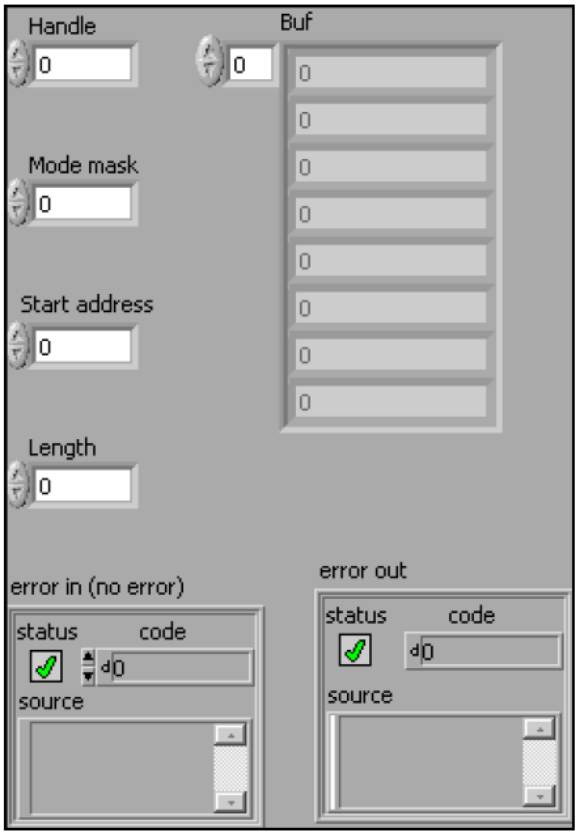
Start address Read start address

Length Read block size

Buffer Read buffer

Numeric

HRM_ReadFIFOMemory.vi



Handle Module handle

Mode mask Mode bits mask

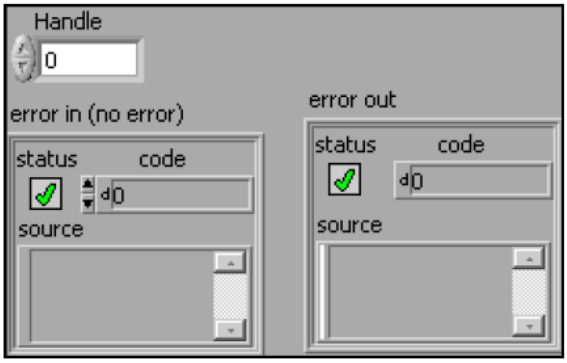
Start address Read start address

Length Read block size

Buf Read buffer

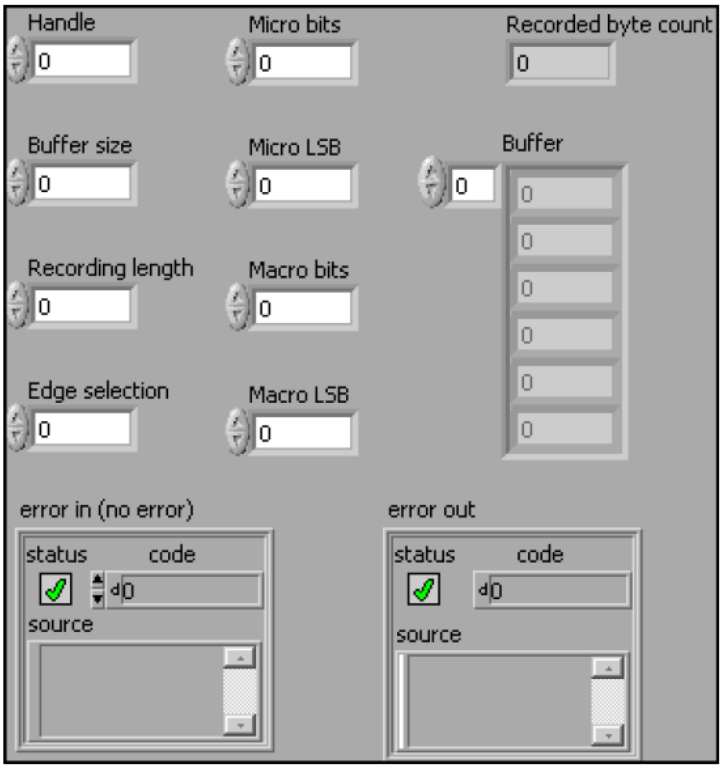
Numeric

HRM_RequestStop.vi



Handle Module handle

HRM_StreamTCSPC2Mem.vi



Handle Module handle

Buffer size Read buffer size

Recording length Recording time in ms

Micro bits Number of microtime bits

Micro LSB Microtime least significant bit

Macro bits Number of macrotime bits

Macro LSB Macrotime least significant bit

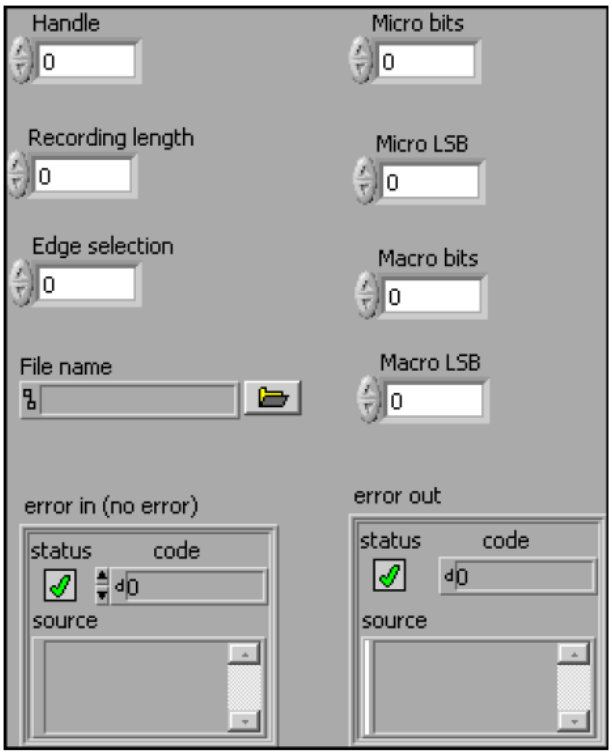
Edge selection Edge selection data

Recorded byte count Number of recorded bytes

Buffer

Numeric Read buffer

HRM_StreamTCSPC2File.vi



Handle Module handle

Recording length Recording time in ms

Micro bits Number of microtime bits

Micro LSB Microtime least significant bit

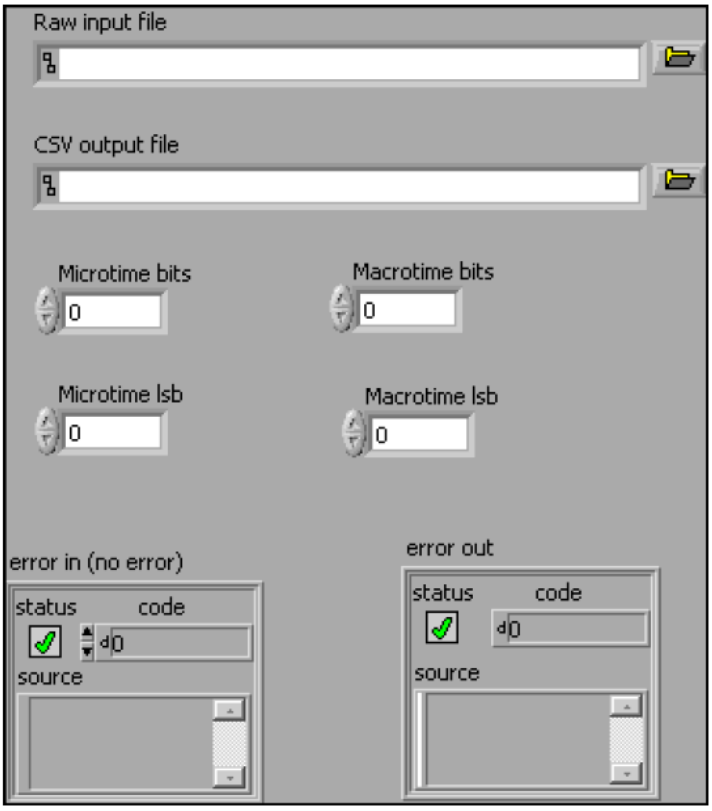
Macro bits Number of macrotime bits

Macro LSB Macrotime least significant bit

File name Output filename

Edge selection Edge selection data

HRM_ConvertRawTCSPCFile2CSV.vi



Raw input file Input (raw) filename

CSV output file Output (CSV) filename

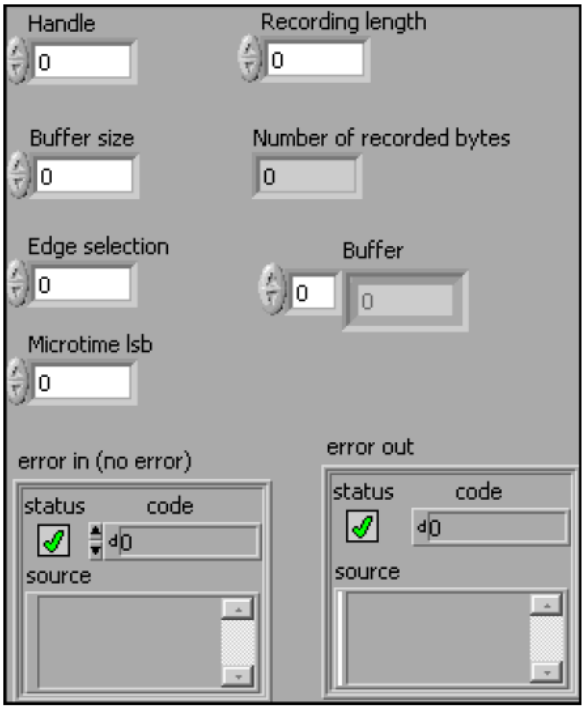
Microtime bits Number of microtime bits (must match the value used in the **HRM_StreamTCSPC2File** call)

Microtime lsb Microtime least significant bit (must match value used for the **HRM_StreamTCSPC2File** call)

Macrotime bits Number of macrotime bits (must match the value used for the **HRM_StreamTCSPC2File** call)

Macrotime lsb Macrotime least significant bit (must match value used for the **HRM_StreamTCSPC2File** call)

HRM_StreamTimeTags2Mem.vi



Handle Module handle

Buffer size Read buffer size

Recording length Recording time in ms

Edge selection Edge selection data

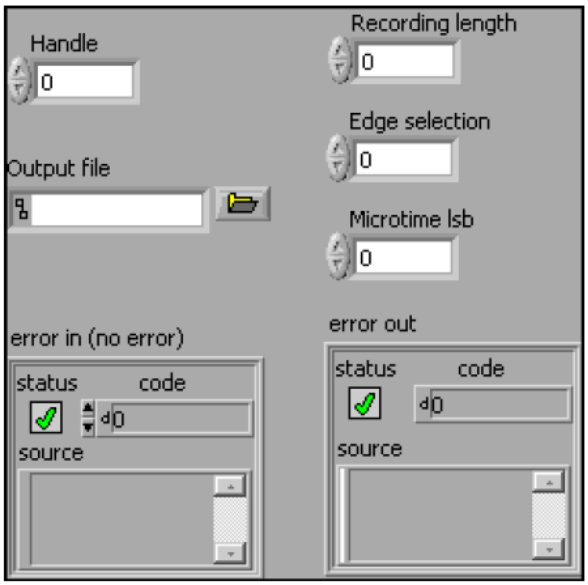
Microtime lsb Microtime least significant bit

Number of recorded bytes Number of recorded bytes

Buffer

Numeric Read buffer

HRM_StreamTimeTags2File.vi



Handle Module handle

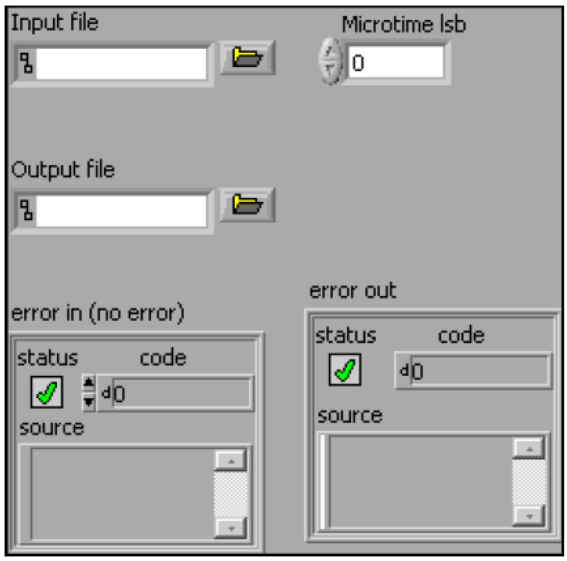
Output file Output filename

Recording length Recording time in ms

Edge selection Edge selection data

Microtime lsb Microtime least significant bit

HRM_ConvertRawContTTagsFile2CSV.vi



Input file Input (raw) filename

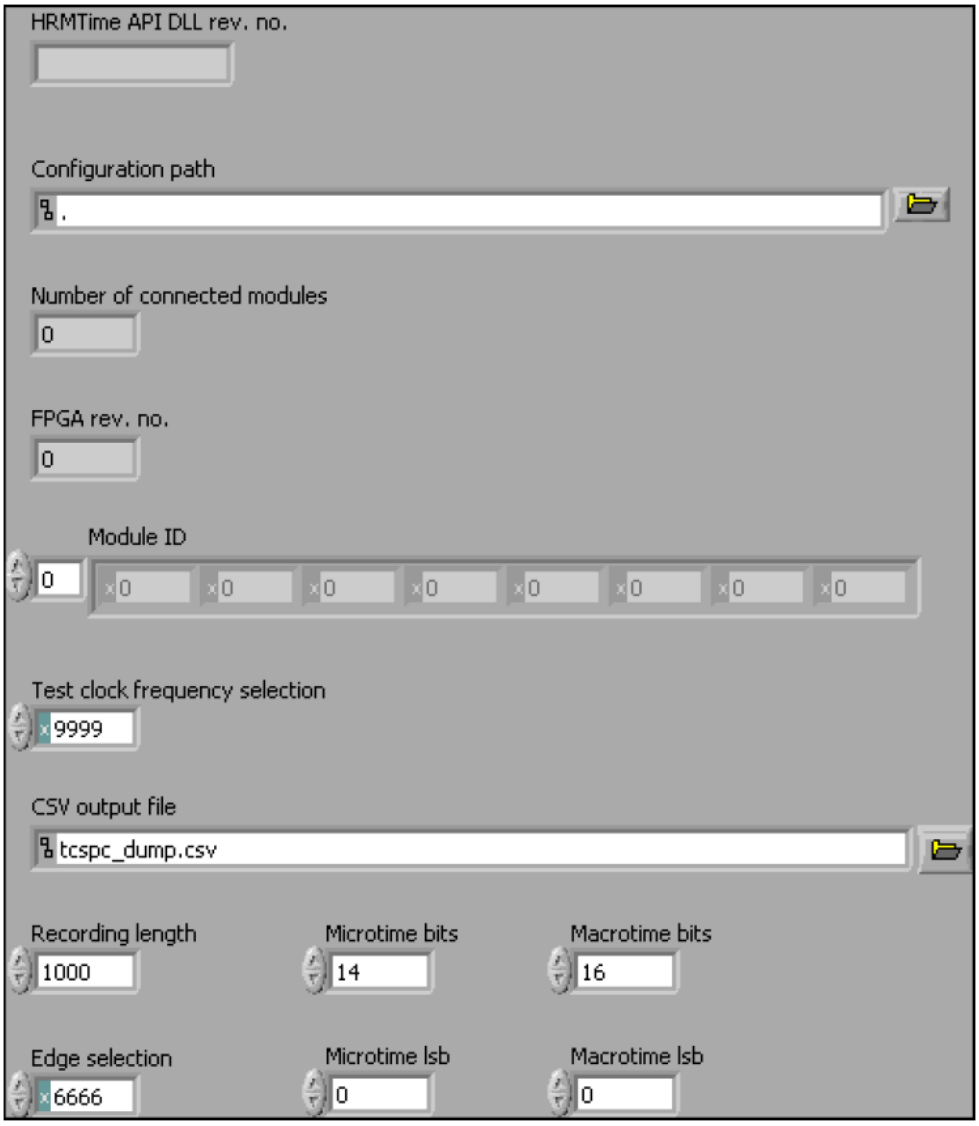
Output file Output (CSV) filename

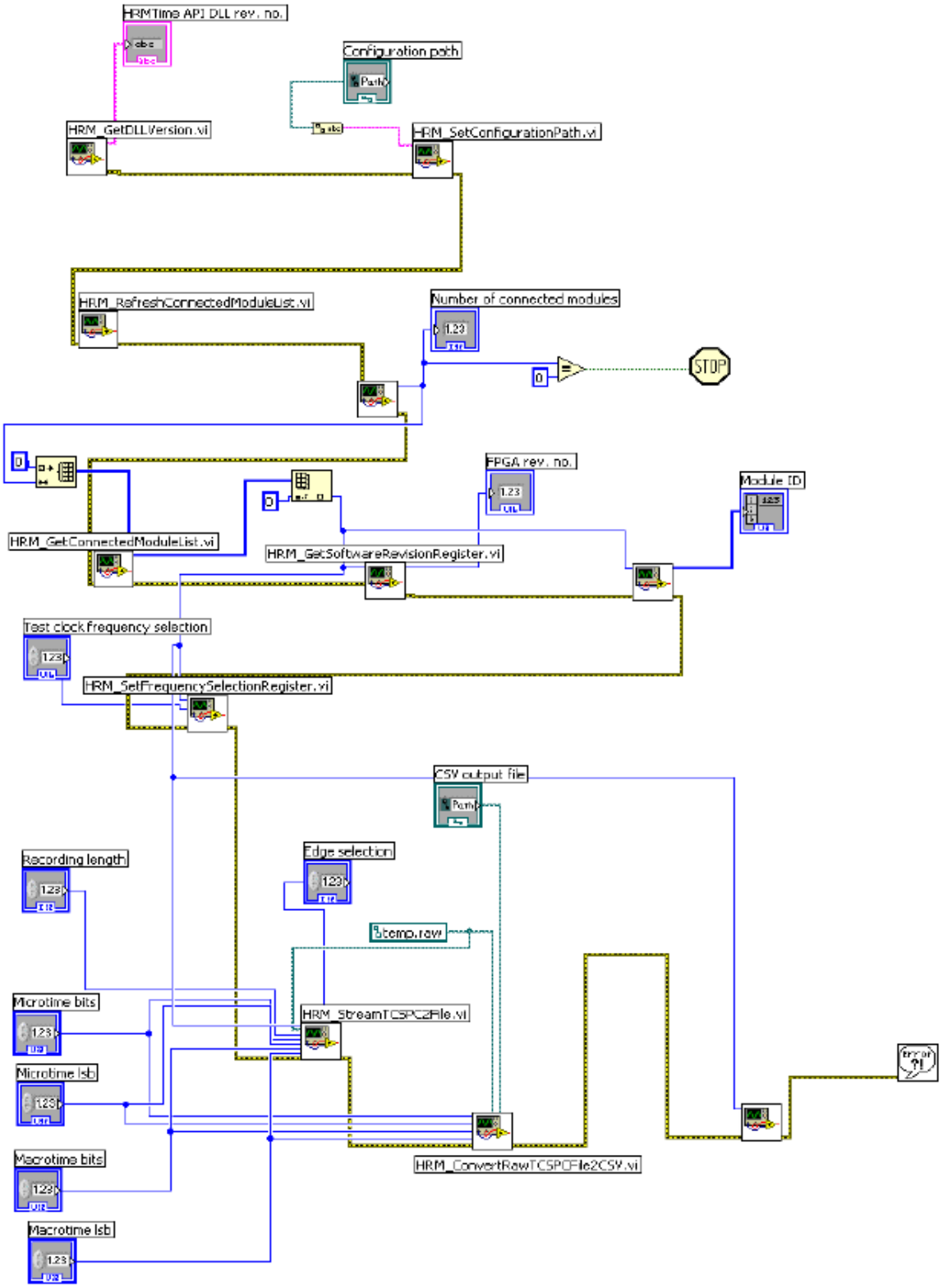
Microtime lsb Microtime least significant bit (must match the value used for the HRM_StramTimeTags2File call)

Sample LabView Application

Test_TCSPC.vi

This is a sample application demonstrating the TCSPC stream-to-file functionality.




HRM Time API DLL rev. no.
Configuration path
Path
HRM_GetDLLVersion.vi
HRM_SetConfigurationPath.vi
HRM_RefreshConnectedModuleList.vi
Number of connected modules
1.23
0
STOP
FPGA rev. no.
Module ID
HRM_GetConnectedModuleList.vi
HRM_GetSoftwareRevisionRegister.vi
Test clock frequency selection
HRM_SetFrequencySelectionRegister.vi
CSV output file
Recording length
Edge selection
temp.raw
Microtime bits
HRM_StreamTCSPC2File.vi
Microtime lsb
Macrotime bits
Macrotime lsb
HRM_ConvertRawTCSPCFile2CSV.vi