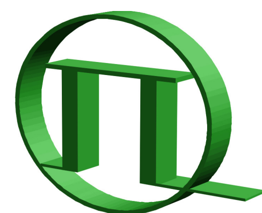
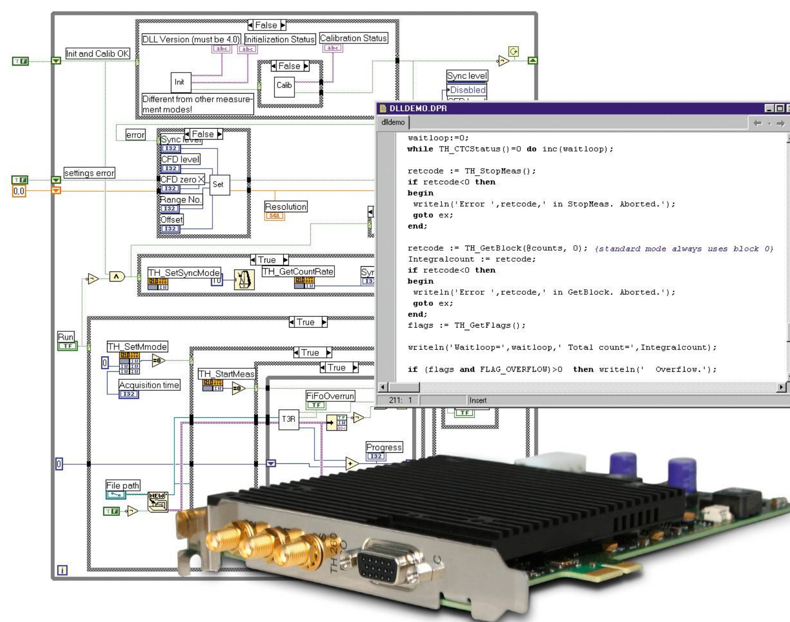
TimeHarp 260

TCSPC and MCS Board with
PCIe Interface



PicoQuant GmbH
Unternehmen für optoelektronische
Forschung und Entwicklung

TH260Lib – Programming Library for Custom Software Development



User's Manual

Version 3.2.0.0

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1. Introduction

The TimeHarp 260 is a cutting edge TCSPC system with PCIe (Peripheral Component Interconnect express) interface. Its new integrated design provides a flexible number of input channels at reasonable cost and allows innovative measurement approaches. The timing circuits allow high measurement rates up to 40 million counts per second (Mcps) and provide a very high time resolution. There are two versions of the TimeHarp 260. The PICO version (TimeHarp 260 P) has a resolution of 25 ps and a deadtime of 25 ns whereas the NANO version (TimeHarp 260 N) provides a time resolution of 250 ps[1)] with a deadtime of less than 2 ns. The modern PCIe interface provides very high throughput as well as 'plug and play' installation. The input triggers are programmable for a wide range of input signals. In case of the PICO version they have a programmable Constant Fraction Discriminator (CFD) for negative going signals while the NANO version provides level triggers for both negative and positive going signals. These specifications qualify the TimeHarp 260 for use with most common single photon detectors such as Single Photon Avalanche Diodes (SPADs) and Photomultiplier Tube (PMT) modules (via preamplifier). The best time resolution is obtained by using Micro Channel Plate PMTs (MCP–PMT) or modern SPAD detectors together with the PICO version. The width of the overall Instrument Response Function (IRF) can then be as small as 40 ps FWHM. Both models of the TimeHarp 260 can be purchased with 2 or 3 timing inputs[2)]. The use of these inputs is very flexible. In fluorescence lifetime applications the first channel is typically used as a synchronization input from a laser. The other input(s) are then used for photon detectors. In coincidence correlation applications all inputs can be used for photon detectors.

The TimeHarp 260 can operate in various modes to adapt to different measurement needs. The standard histogram mode performs real–time histogramming in computer memory. Two different Time–Tagged–Time–Resolved (TTTR) modes allow recording of each photon event on separate, independent channels, thereby providing unlimited flexibility in off–line data analysis such as burst detection and time–gated or lifetime weighted Fluorescence Correlation Spectroscopy (FCS) as well as picosecond coincidence correlation, using the individual photon arrival times.

The TimeHarp 260 standard software provides functions such as the setting of measurement parameters, display of results, loading and saving of measurement parameters and histogram curves. Important measurement characteristics such as count rate, count maximum and position, histogram width (FWHM) are displayed continuously. While these features will meet many of the routine demands, advanced users may want to include the TimeHarp's functionality in their own automated measurement systems with their own software. In particular where the measurement must be interlinked or synchronized with other processes or instruments this approach may be of interest. For this purpose a programming library is provided as a Dynamic Link Library (DLL) for Windows[3)]. It supports custom programming in all major programming languages, notably C / C++, C#, Delphi / Lazarus, LabVIEW and MATLAB. A Linux version of the library for the x86-64 architecture is also available (see the separate manual).

This manual describes the installation and use of the TimeHarp programming library for Windows and explains the associated demo programs. Please regard the demo code as part of the documentation. Also read both this manual and the TimeHarp manual before beginning your own software development with the DLL. The TimeHarp 260 is a sophisticated real–time measurement system. In order to work with the system using the DLL, sound knowledge in your chosen programming language is required.

For more information on the TimeHarp 260 hardware and software please consult the TimeHarp 260 manual. For details on the method of Time–Correlated Single Photon Counting, please refer to our TechNote on TCSPC.

1) TimeHarp 260 N manufactured before 2016 have a resolution of 1 ns but can be returned for an upgrade to 250 ps at moderate cost.
2) Note that the choice of model (SINGLE/DUAL) also has an impact on other functionality such as marker signals in TTTR mode.
3) Trademark of Microsoft Inc.

2. Release Notes

2.1. What's new in this version

The present version 3.2.0.0 of TH260Lib is a bugfix release that corrects an issue with small time shifts (a few hundred ps) on the histogram time axis, occurring from one hardware initialization to the next. It furthermore fixes an inversion of the selected input edge (TimeHarp 260 NANO only). Due to the functional significance of this change the version number was bumped up at the second digit. The new release furthermore fixes an issue with warnings occasionally being incorrect at the time of first retrieval after initialization. It also provides some minor documentation updates. The data formats and interfaces remain unchanged. The set of demos has been extended to inlcude Python and the LabVIEW demos have been significantly refurbished.

What was new in version 3.1.0.3:

This version of TH260Lib was a bugfix release that solved an issue with sporadic timeout errors upon hardware initialization and an issue where errors occurred on stopping a measurement when Windows was set to 1 or 2 ms timer resolution by other software. It also provided a new driver to support Windows 10 with “secure boot” enabled. It furthermore fixed some minor documentation errors. The data formats and interfaces remained unchanged.

What was new in version 3.1.0.2:

This was a bugfix release that solved an issue where TH260_StopMeas failed on some PCs. This required a redesign of the internal multithreading concept. The positive side effect was a small improvement in histogramming throughput at reduced CPU load. The interface and data structures remained unchanged so that programs written for version 3.1.x need no changes. Programs written for version 3.0.x only require the adaption of version checking.

The last major release 3.1.0.1 provided these new features:

- support of new hardware versions manufactured after February 2017 (firmware 2.x).
- histogramming throughput improvements
- fix of an issue where debug information was not properly retrieved via TH260_GetHardwareDebugInfo after initialization failures
- interface and data structures remained unchanged w.r.t. version 3.0

One internal change from v. 3.0 to 3.1 that should be noted is the new alignment requirement of the data buffer passed to TH260_ReadFiFo. The memory buffer must now be aligned on a 4096-byte boundary (memory page boundary) in order to allow efficient DMA transfers. If your buffer does not meet this requirement the library will use an internal buffer and copy the data. This slows down data throughput.

The previous major release 3.0 provided these new features:

- Support of the latest hardware improvement of the TimeHarp 260 N - now running at 250 ps resolution[1)]
- Officiall support of Windows 10
- Some minor bugfixes
- Updated demos
- API and data formats remain unchanged

The previous major release 2.0 provided these new features:

- A new device driver with improved error handling and automated installation
- A new library routine SetInputDeadTime for suppression of some detector artefacts.
  (Note that this works only for TimeHarp 260 P purchased after April 2015. Old boards can be updated but must be returned to PicoQuant for this purpose.)
- A bugfix in the shutdown code called upon unloading the library
- Some small demo code improvements
- Some documentation fixes

1) TimeHarp 260 N manufactured before 2016 have a resolution of 1 ns but can be returned for an upgrade to 250 ps at moderate cost.

Interface changes (if any) are marked in red in section 7.2 listing the individual library routines. See the notes there for synopsis and hints.

2.2. General Notes

This version of the TimeHarp 260 programming library is suitable for Windows[1] 8.1 and 10 [2] (32 or 64 bit). Older Windows versions may still work but are no longer officially supported. Also consider the security risks of using an outdated operating system. Future Windows versions are likely to work but obviously cannot be tested before they are released, and are therefore not formally supported.

The library has been tested with MinGW 2.0 (free compiler for Windows, 32 bit), MSVC++ 6.0 (32 bit), Visual C++ 2019 (32/64 bit), Visual C# 2010 (32/64 bit), Borland C++ 5.5 (32 bit), as well as with Python 3.7.4, Delphi 10.1 (64 bit), Lazarus 1.2.4 (32/64 bit), LabVIEW 2017 (32/64 bit) and MATLAB R2019b, (64 bit).

This manual assumes that you have read the TimeHarp 260 manual and that you have solid experience with the chosen programming language. References to the TimeHarp manual will be made where necessary.

The library supports histogramming mode and both TTTR modes but your TimeHarp 260 board must have the library option enabled. If you have not initially purchased the library option (license) you can upgrade it any time later.

Users who own a license for any older version of the library will receive free updates when they are available. For this purpose, please check the PicoQuant web site or write an email to *info@picoquant.com*.

Users upgrading from earlier versions of `TH260Lib` may need to adapt their programs. This is the price for technical progress. Some changes are usually necessary to accommodate new measurement modes and improvements. However, the required changes are usually minimal and will be explained in the manual (especially check section 4.1 and any notes marked in red in section 7.2).

Note that despite of our efforts to keep changes minimal, data structures, program flow and function calls may change in future versions without advance notice. Users must maintain appropriate version checking in order to avoid incompatibilities. There is a function call tat you can use to retrieve the version number (see section 7.2). Note that this call returns only the major two digits of the version (e.g. 3.2). The DLL actually has two further sub–version digits, so that the complete version number has four digits (e.g. 3.2.0.0). They are shown only in the Windows file properties. These sub–digits help to identify intermediate versions that may have been released for minor updates or bug fixes. The interface of releases with identical major version will remain the same.

1) Trademark of Microsoft Inc.
2) Given that Windows 10 is perpetually changing by way of major updates this is valid as of February 2020.

2.3. Warranty and Legal Terms

Disclaimer

PicoQuant GmbH disclaims all warranties with regard to the supplied software and documentation including all implied warranties of merchantability and fitness for a particular purpose. In no case shall PicoQuant GmbH be liable for any direct, indirect or consequential damages or any material or immaterial damages whatsoever resulting from loss of data, time or profits; arising from use, inability to use, or performance of this software and associated documentation. Demo code is provided 'as is' without any warranties as to fitness for any purpose.

License and Copyright

With the TimeHarp 260 DLL option you have purchased a license to use the TimeHarp 260 programming library. You have not purchased any other rights to the software itself. The software is protected by copyright and intellectual property laws. You may not distribute the software to third parties or reverse engineer, decompile or disassemble the software or part thereof. You may use and modify demo code to create your own software. Original or modified demo code may be re–distributed, provided that the original disclaimer and copyright notes are not removed from it. Copyright of this manual and on–line documentation belongs to PicoQuant GmbH. No parts of it may be reproduced, translated or transferred to third parties without written permission of PicoQuant GmbH.

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3. Installation of the TH260Lib Software Package

TH260Lib and its demos will not be installed by the standard TimeHarp 260 software setup. The standard "interactive" TimeHarp 260 data acquisition software does not require the DLL, which is provided for custom application programming only. Vice versa, your custom program will only require the DLL and driver, but not the standard TimeHarp 260 data acquisition software. Installing both the standard TimeHarp software and DLL–based custom programs on the same computer is possible, but only one program at a time can use one TimeHarp 260.

To install TH260Lib, please back up your work and uninstall any previous versions of TH260Lib. Then run the setup program `SETUP.EXE` in the `TH260Lib` folder on the installation disc. If you received the setup files as a ZIP archive, please unpack them to a temporary directory on your hard drive and run `SETUP.EXE` from there. You will need administrator rights to perform the setup including driver installation. If the setup is performed by an administrator but used from other accounts without full access permission to all disk locations, these restricted accounts may not be able to run the demos in the default locations they have been installed to. In such cases it is recommended that you copy the demo directory (or selected files from it) to a dedicated development directory, in which you have the necessary rights (e.g. in 'My Documents').

You also need to install the TimeHarp 260 device if you have not done so before (see your TimeHarp manual). The programming library will access the TimeHarp 260 through a dedicated device driver. The driver is installed by setup.exe. Both the standard TimeHarp software distribution as well as the TH260Lib distribution media contain the driver package and the respective setup programs will install it. Repeated installation of the driver does not harm. If you wish to uninstall the driver package you can do so via the regular windows software management facilities. Do not delete it from within the Windows Device Manager.

Note that multiple devices can be controlled through TH260Lib. After installing the device(s) and the software you can use the Windows Device Manager to check if they have been detected and the driver is correctly installed. On some Windows versions you may need administrator rights to perform setup tasks. Refer to your TimeHarp 260 manual for other installation details.

It is recommended to start your work with the TimeHarp 260 by using the standard interactive TimeHarp data acquisition software. This should give you a better understanding of the system's operation and you can be sure everything works before you begin your own programming efforts. As a next step, see the subfolder `\demos` in your TH260Lib installation folder for sample code that can be used as a starting point for your own programs.

The TH260Lib package provides both 32-bit and 64-bit versions of the library. On a 64-bit version of Windows the setup program will install both versions of the DLL. On a 32-bit version it will only install the 32-bit version. Note that the 32-bit version of the DLL is named TH260Lib.dll while the 64-bit version is named TH260Lib64.dll. This is to avoid confusions between the two. As a consequence of the different names the demo code is slightly version dependent and will be installed in two separate folders for 32-bit and 64-bit. For reference and comparison the demos will always be fully installed in both versions but obviously the 64-bit versions will not run on a 32-bit version of Windows.

4. The Demo Applications

4.1. Functional Overview

Please note that all demo code provided is correct to our best knowledge, however, we must disclaim all warranties as to fitness for a particular purpose of this code. It is provided 'as is' for no more than explanatory purposes and a starting point for your own work.

Because the TCSPC data acquisition requires real–time processing and / or real–time storing of data, the work with the DLL is demanding both in programming skills and computer performance.

The demos are kept as simple as possible to maintain focus on the key issues of accessing the library. This is why most of the demos have a minimalistic user interface and / or run from the simple command box (console). For the same reason, the measurement parameters are mostly hard–coded and thereby fixed at compile time. It is therefore necessary to change the source code and re-compile the demos in order to run them in a way that is matched to your individual measurement setup. Running them unmodified will probably result in useless data (or none at all) because of inappropriate sync divider, resolution, input level settings, etc.

For the same reason of simplicity, the demos will always only use the first TimeHarp 260 device they find, although the library can support multiple devices. If you have multiple devices that you want to use simultaneously you need to change the code to match your configuration.

There are demos for C / C++, C#, Delphi / Lazarus, LabVIEW and MATLAB. For each of these programming languages / systems there are different demo versions for various measurement modes:

Histogramming Mode Demos

These demos show how to use the standard measurement mode for classic TCSPC histogramming. These are the simplest demos and the best starting point for your own experiments. In case of LabVIEW the standard mode demo is more sophisticated and allows interactive input of most parameters.

TTTR Mode Demos

These demos show how to use TTTR mode, i.e. recording individual photon events instead of forming histograms of stop-start differences. This permits advanced data analysis methods, such as single molecule burst detection, the combination of fluorescence lifetime measurement with FCS and picosecond coincidence correlation or even Fluorescence Lifetime Imaging (FLIM).

The TimeHarp 260 actually supports two different Time–Tagging modes, T2 and T3 mode. When referring to both modes together we use the general term TTTR. For details on the two modes, please refer to your TimeHarp manual. In TTTR mode it is also possible to record external TTL signal transitions as markers in the TTTR data stream which is typically used e.g. for FLIM. Note that this requires the TimeHarp 260 DUAL model. For more information see the section about TTTR mode in your TimeHarp manual.

Note that you must not call any of the `TH260_Setxxx` routines while a TTTR measurement is running. The result would potentially be loss of events in the TTTR data stream. Changing settings during a measurement usually makes no sense anyway, since it would introduce inconsistency.

The TTTR mode demos only show how to perform the data acquisition. In order to keep the demos simple the data is only stored to disk but not interpreted (except the advanced LabVIEW demos). If you wish to interpret and analyze the TTTR mode data "on the fly" while data is being collected, please study the TTTR file demos installed as part of the regular interactive TimeHarp software. These show how to do the bitwise interpretation of the TTTR data records. Note that such a real-time analysis of the TTTR data requires sufficient performance of your programming environment. Compiled native code obtained with C/C++ or Pascal performs significantly better in this regard than Matlab, Python and LabVIEW.

4.2. The Demo Applications by Programming Language

As outlined above, there are demos for C / C++, Delphi / Lazarus, C#, LabVIEW and MATLAB. For each of these programming languages / systems there are different demo versions for the measurement modes listed in the previous section. They are not 100% identical.

This manual explains the special aspects of using the TimeHarp programming library, it does NOT teach you how to program in the chosen programming language. We strongly recommend that you do not choose a development with the TimeHarp programming library as your first attempt at programming. You will also need some knowledge about Windows DLL concepts and calling conventions. The ultimate reference for details about how to use the DLL is in any case the source code of the demos and the header files of TH260Lib (`th260lib.h` and `th260defin.h`).

Be warned that wrong parameters and / or variables, invalid pointers and buffer sizes, inappropriate calling sequences etc. may crash your application and / or your complete computer. This may even be the case for relatively safe operating systems because you are accessing a kernel mode driver through `TH260Lib`. This driver has high privileges at kernel level, that provide all power to do damage if used inappropriately. Make sure to back up your data and / or perform your development work on a dedicated machine that does not contain valuable data. Note that the DLL is not fully re-entrant. This means, it cannot be accessed arbitrarily from multiple, concurrent processes or threads at the same time. Only calls accessing different devices can be made concurrently. All calls to one individual device must be made sequentially. While most calls for setting up parameters can be made in arbitrary oder, it is clear that calls for starting and stopping of measurements and those for fetching data must be made in a meaningful sequence. It is recommended to follow the order of calls shown in the demos.

Note that for the 64-bit versions different names apply. The main 64-bit DLL file is named `TH260Lib64.dll` and the 64-bit link library is named `TH260Lib64.lib`. This is to avoid confusion between the two versions. As a consequence of the different names the demo code is version dependent and will be installed in two separate folders for 32-bit and 64-bit. In the following we use the 32-bit library names without the suffix `64`.

The C / C++ Demos

These demos are provided in the `C` subfolder. The code is actually plain C to provide the smallest common denominator for C and C++. Consult `th260lib.h`, `th260defin.h` and this manual for reference on the library calls. The library functions must be declared as `extern "C"` when used from C++. This is achieved most elegantly by wrapping the entire include statements for the library headers:

```
extern "C"
{
  #include "th260defin.h"
  #include "th260lib.h"
}
```

In order to make the exports of `TH260Lib.dll` known to the rest of your application you may want to link directly with the import library `TH260Lib.lib`. `TH260Lib.lib` was created for MSVC 6.0 or higher, with symbols decorated in Microsoft style. MSVC++ users who have version 6.0 or higher can use the supplied project files (`*.dsw`) where linking with `TH260Lib.lib` is already set up. More recent versions of MSVC will be able to import these project files. The DLL also (additionally) exports all symbols undecorated, so that other compilers should be able to use them conveniently, provided they understand the Microsoft LIB format or they can create their own import library. The MinGW compiler understands the Microsoft format. With Borland C++ 5.x and C++Builder you can use the Borland Utility IMPLIB to create your own import library very easily:

```
implib TH260Lib_bc.lib TH260Lib.dll
```

It is normal if this gives you warnings about duplicate symbols. Then link your project with the newly created import library `TH260Lib_bc.lib`. Failing to work with an import library you may still load the DLL dynamically and call the functions explicitly.

To test any of the demos, consult the TimeHarp manual for setting up your TimeHarp 260 and establish a measurement setup that runs correctly and generates useable test data. Compare the settings (notably sync divider, binning and CFD levels) with those used in the demo and use the values that work in your setup when building and testing the demos.

The C demos are designed to run in a console ("DOS box"). They need no command line input parameters. They create their output files in their current working directory (`*.out`). The output files will be ASCII-readable in case of the standard histogramming demos. For this demo, the ASCII files will contain one or multiple columns of integer numbers representing the counts in the histogram bins. You can use any editor or a data visualization program to inspect the ASCII histograms. For the TTTR modes the output is stored in binary format for performance reasons. The binary files must be read by dedicated programs according to the format they were written in. The file read demos provided for the TimeHarp TTTR data files can be used as a starting point. They cannot be used directly on the demo output because they expect a file header the demos do not generate. This is intentional in order to keep the TH260Lib demos focused on the key issues of using the library.

By default, the TTTR mode demo is configured for T2 mode. You need to change the mode input variable going into TH260_Initialize to a value of 3 if you want T3 mode. Note that you probably also need to adjust the sync divider and the resolution in this case. See the TimeHarp manual for explanation of the different modes.

The C# Demos

The C# demos are provided in the `Csharp` subfolder. They have been tested with MS Visual Studio 2010 as well as with the open source framework Mono. The only difference is the library name, which in principle could also be unified.

Calling a native DLL (unmanaged code) from C# requires the `DllImport` attribute and correct type specification of the parameters. Not all types are easily portable. Especially C strings require special handling. The demos show how to do this.

With the C# demos you also need to check wether the hardcoded settings are suitable for your actual instrument setup. The demos are designed to run in a console ("DOS box"). They need no command line input parameters. They create their output files in their current working directory (*.out). The output files will be ASCII in case of the histogramming demos. For TTTR mode the output is stored in binary format for performance reasons. The ASCII files will contain single or multiple columns of integer numbers representing the counts from the histogram channels. You can use any editor or a data visualization program to inspect the ASCII histograms. The binary files must be read by dedicated programs according to the format they were written in.

The Python Demos

The Python demos are in the `Python` folder. Python users should start their work in histogramming mode from `histomode.py`. The code should be fairly self explanatory. If you update to a new library version please check the function parameters of your existing code against `th260lib.h` in the TH260Lib installation directory. Note that special care must be taken where pointers to C–arrays are passed as function arguments.

The Python demos create output files in their current working directory (`*.out`). The output file will be readable text in case of the standard histogramming demo. The files will contain columns of integer numbers representing the counts from the histogram channels. You can use any data visualization program to inspect the histograms. In TTTR mode the output is stored in binary format for performance reasons. The binary files must be read by dedicated programs according to the format they were written in. The file read demos provided for the TimeHarp TTTR data files can be used as a starting point. They cannot be used directly on the demo output because they expect a file header the demos do not generate. This is intentional in order to keep the TH260Lib demos focused on the key issues of using the library.

By default, the TTTR mode demo is configured for T2 mode. This will not allow you to work with high sync rates. You need to change the `mode` input variable going into `TH260_Initialize` to a value of 3 if you want T3 mode. At the same time you need to modify your program for an appropriate sync divider and a suitable range (resolution).

The Delphi / Lazarus Demos

Delphi or Lazarus users refer to the `Delphi` folder. The source code for Delphi and Lazarus is the same. Everything for the respective Delphi demo is in the project file for that demo (`*.DPR`). Lazarus users can use the `*.LPI` files that refer to the same `*.DPR` files.

In order to make the exports of `TH260Lib.dll` known to your application you have to declare each function in your Pascal code as 'external'. This is already prepared in the demo source code. `TH260Lib.dll` was created with symbols decorated in Microsoft style. It additionally exports all symbols undecorated, so that you can call them from Delphi with the plain function name. Please check the function parameters of your code against `th260lib.h` in the demo directory whenever you update to a new DLL version.

The Delphi / Lazarus demos are also designed to run in a console ("DOS box"). They need no command line input parameters. They create output files in their current working directory. The output files will be ASCII in case of the histogramming demo. In TTTR mode the output is stored in binary format for performance reasons. You can use any data visualization program to inspect the ASCII histograms. The binary files must be read by dedicated programs according to the format they were written in. The file read demos provided for the TimeHarp 260 TTTR data files can be used as a starting point. They cannot be used directly on the demo output because they expect a file header the demos do not generate. This is intentional in order to keep the demos focused on the key issues of using the library.

By default, the TTTR mode demo is configured for T2 mode. This will not allow you to work with high sync rates. You need to change the mode input variable going into TH260_Initialize to a value of 3 if you want T3 mode. At the same time you need to modify your program for an appropriate sync divider and a suitable range (resolution).

The LabVIEW Demos

The LabVIEW demo VIs are provided in the src sub-folder inside the LabVIEW20xx folders. They can be run either with 32 bit or 64 bit LabVIEW. The correct DLL (th260lib.dll for 32 bit, th260lib64.dll for 64 bit respectively) is selected automatically, provided that it is located in the designated Windows folder (i.e. SysWOW64 and/or System32). This should be the case after correct installation of the library package. The original demo code was created with LabVIEW 2017, accordingly also a LabVIEW project file (MultiHarp.lvproj) and two executables (MultiHarpHisto.exe and MultiHarpT3.exe; both in build sub-folder) are provided for that version. For backward compatibility the source code was also converted to LabVIEW 2010.

The first LabVIEW demo (`1_SimpleDemo_TH260Histo.vi`) is very simple, demonstrating the basic usage and calling sequence of the provided SubVIs encapsulating the library functionality, which are assembled inside the LabVIEW library `th260lib_x86_x64_UIThread.llb`. The demo starts by calling some of these library functions to setup the hardware in a defined state and continues with a measurement in histogramming mode by calling the corresponding library functions inside a while-loop. Histograms and count rates for all available hardware channels are displayed on the front panel in a waveform graph (you might have to select `AutoScale` for the axes) and numeric indicators, respectively. The measurement is stopped if either the acquisition time has expired, if an error occurs (which is reported in the error out cluster), if an overflow occurs or if the user hits the STOP button.

The second demo for histogramming mode (`2_AdvancedDemo_TH260Histo.vi`) is a more sophisticated one allowing the user to control all hardware settings "on the fly", i.e. to change settings like acquisition time (Acqu. ms), resolution (Resol. ms), offset (Offset ns in Histogram frame), number of histogram bins (Num Bins), etc. before, after or while running a measurement. In contrast to the first demo settings for each available channel (including the Sync channel) can be changed individually (Settings button) and consecutive measurements can be carried out without leaving the program (Run button; changes to Stop after pressing). Additionally, measurements can be done either as "single shot" or in a continuous manner (Conti. Checkbox). Various information are provided on the Front Panel like histograms and count rates for each available (and enabled) channel as waveform graphs (you might have to select `AutoScale` for the axes), Sync rate, readout rate, total counts and status information in the status bar, etc. In case an error occurs a popup window informs the user about that error and the program is stopped.

The program structure of this demo is based upon the National Instruments recommendation for queued message and event handlers for single thread applications. Some comments inside the source code should help the user to get an overview of the program and to facilitate the development of customized extensions.

The third LabVIEW demo (3_AdvancedDemo_TH260T3.vi) is the most advanced one and demonstrates the usage of T3 mode including real-time evaluation of the collected TTTR records. The front panel resembles the second demo but in addition to the histogram display a second waveform graph (you might have to select AutoScale for the axes) also displays a time chart of the incoming photons for each available (and enabled) channel with a time resolution depending on the Sync rate and the entry in the Resol. ms control inside the Time Trace frame (which can be set in multiples of two). In contrast to the second demo there is no control to set an overflow level or the number of histogram bins, which is fixed to 32.768 in T3 mode. Also in addition to the acquisition time (called T3Acq. ms in this demo; set to 360.000.000 ms = 100 h by default) a second time (Int.Time ms in Histogram frame) can be set which controls the integration time for accumulating a histogram.

The program structure of this demo extends that of the second demo by extensive use of LabVIEW type-definitions and two additional threads: a data processing thread (TH260_DataProcThread.vi) and a visualization thread. The communication between these threads is accomplished by LabVIEW queues. Thereby the FiFo read function (case ReadFiFo in UIThread) can be called as fast as possible without any additional latencies from data processing workload.

Some comments inside the source code should help the user to get an overview of the program and to facilitate the development of customized extensions. Please note that due to performance reasons some of the SubVIs inside TH260_DataProcThread.vi have been inlined for performance, so that no debugging is possible on these SubVIs.

Program specific SubVIs and type-definitions used by the demos are organized in corresponding sub-folders inside the demo folder. General helper functions and type-definitions as well as encapsulating LabVIEW libraries (*.llb) can be found in the _lib folder (containing further sub-folders) inside the demo folder. In order to facilitate the use of all library functions, additional VIs called TH260_AllDllFunctions_xxx.vi have been included. These VIs are not meant to be executed but should only give a structured overview of all available library functions and their required context.

Please note:

In addition to the library used by the demos (th260lib_x86_x64_UIThread.llb) a second LabVIEW library (llb) is included allowing the library calls to be executed in any thread of LabVIEWs threading engine (th260lib_x86_x64_AnyThread.llb). This llb is intended for time critical applications where user actions on the front panel (like e.g., resizing or moving) must not affect the execution of a data acquisition thread containing these library functions (please refer to “Multitasking in LabVIEW”: http://zone.ni.com/reference/en-XX/help/371361P-01/lvconcepts/multitasking_in_labview/). When using this llb you have to make sure that all library functions are called in a sequential order to avoid errors or even program crashes. Also be aware that library functions in th260lib_x86_x64_AnyThread.llb have the same names as in th260lib_x86_x64_UIThread.llb and opening both libraries at the same time would lead to name conflicts. Therefore, only experienced users should use th260lib_x86_x64_AnyThread.llb.

The MATLAB Demos

The MATLAB demos are provided in the MATLAB folder. They are contained in .m files. You need to have a MATLAB version that supports the loadlibrary and calllib commands. The earliest version we have tested is MATLAB 7.3 but any version from 6.5 should work. Note that recent versions of MATLAB require a compiler to be installed for work with DLLs. We tested with MATLAB R2019b and MinGW-w64 19.2.0. For your specific version of MATLAB, please check the documentation of the MATLAB command loadlibrary as to which compilers it supports. Be careful about the header file name specified in loadlibrary. The names are case sensitive and a wrong spelling will lead to an apparently successful load - but later no library calls will work.

The MATLAB demos are designed to run inside the MATLAB console. They need no command line input parameters. They create output files in their current working directory. The output file will be ASCII in case of the histogramming demo. In TTTR mode the output is stored in binary format for performance reasons. You can use any data visualization program to inspect the ASCII histograms. The binary files must be read by dedicated programs according to the format they were written in. The file read demos provided for the TimeHarp 260 TTTR data files can be used as a starting point. They cannot be used directly on the demo output because they expect a file header the demos do not generate. This is intentional in order to keep the demos focused on the key issues of using the library.

By default, the TTTR mode demo is configured for T2 mode. This will not allow you to work with high sync rates. You need to change the mode input variable going into `TH260_Initialize` to a value of 3 if you want T3 mode. At the same time you need to modify your program for an appropriate sync divider and a suitable range (resolution).

5. Advanced Techniques

5.1. Using Multiple Devices

The library is designed to work with one or more TimeHarp 260 devices (up to 4). The demos always use the first device found. If you have more than one TimeHarp 260 and you want to use them together you need to modify the code accordingly. At the API level of TH260Lib the devices are distinguished by a device index (0 .. 3). The device order corresponds to the order Windows enumerates the devices. It may therefore be difficult to know which physical device corresponds to the given device index. In order to solve this problem, the library routine `TH260_OpenDevice` provides a second argument through which you can retrieve the serial number of the physical device at the given device index. Similarly you can use `TH260_GetSerialNumber` any time later on a device you have successfully opened. The serial number of a physical TimeHarp device can be found at the back of the PCB as well as in your delivery note. It is a 8 digit number starting with 0100. The leading zero will not be shown in the serial number strings retrieved through `TH260_OpenDevice` or `TH260_GetSerialNumber`. If you install multiple devices in one PC it is a good idea to write down the serial nubers and their respective installation slots.

As outlined above, if you have more than one TimeHarp and you want to use them together you need to modify the demo code accordingly. This requires briefly the following steps: Take a look at the demo code where the loop for opening the device(s) is. In most of the demos all the available devices are opened. You may want to extend this so that you

1. filter out devices with a specific serial number and
2. do not hold open devices you don't actually need.

The latter is recommended because a device you hold open cannot be used by other programs such as the regular TimeHarp software.

By means of the device indices you picked out you can then extend the rest of the program so that every action taken on the single device is also done on all devices of interest, i.e. initialization, setting of parameters, starting a measurement etc. At the end the demos close all devices. It is recommended to keep this approach. It does no harm if you close a device that you haven't opened.

5.2. Efficient Data Transfer

The TTTR modes are designed for fast real–time data acquisition. TTTR mode is most efficient in collecting data with a maximum of information. It is therefore most likely to be used in sophisticated on–line data processing scenarios, where it may be worth optimizing data throughput.

In order to achieve the highest throughput the TimeHarp 260 uses busmaster DMA transfers. This is supported by the PC hardware that can transfer data to the host memory without much help of the CPU. For the TimeHarp this permits data throughput as high as 40 Mcps and leaves time for the host to perform other useful things, such as on–line data analysis, data display, or storing data to disk.

In TTTR mode the data transfer process is exposed to the DLL user in a single function `TH260_ReadFiFo` that accepts a buffer address where the data is to be placed, and a transfer block size. This block size is critical for efficient transfers. The larger the block size, the better the transfer efficiency. This is because setting up a transfer costs some fixed amount of time, independent of the block size. The maximum transfer block size is 131,072 (128k event records). However, it may not under all circumstances be ideal to use the maximum size. The minimum size is 128.

Note that the memory buffer you pass to `TH260_ReadFiFo` must be aligned on a 4096-byte boundary (memory page boundary) in order to allow efficient DMA transfers. If your buffer does not meet this requirement the library will use an internal buffer and copy the data. This slows down data throughput.

As noted above, the transfer is implemented efficiently without using the CPU excessively. Nevertheless, assuming large block sizes, the transfer takes some time. Windows therefore gives the unused CPU time to other processes or threads i.e. it waits for completion of the transfer without burning CPU time. This wait time is what can also be used for doing 'useful things' in terms of any desired data processing or storing within your own application. The proper way of doing this is to use multi-threading. In this case you design your program with two threads, one for collecting the data (i.e. working with `TH260_ReadFiFo`) and another

for processing or storing the data. Multiprocessor systems can benefit from this technique even more. Of course you need to provide an appropriate data queue between the two threads and the means of thread synchronization. Thread priorities are another issue to be considered. Finally, if your program has a graphic user interface you may need a third thread to respond to user actions reasonably fast. Again, this is an advanced technique and cannot be demonstrated in detail here. Greatest care must be taken not to access the TH260Lib DLL from different threads without strict control of mutual exclusion and maintaining the right sequence of function calls. However, the technique also allows throughput improvements of 50% .. 100% and advanced programmers may want to use it. It might be interesting to note that this is how TTTR mode is implemented in the regular TimeHarp software, where sustained count rates as high as 40 Mcps (to disk) can be achieved. It is also worth noting that compiled native code obtained with C/C++ or Pascal performs significantly better in real-time TTTR data analysis than Matlab and LabVIEW.

In case of using multiple devices it is also beneficial for overall throughput if you use multi-threading in order to fetch and store data from the individual devices in parallel. Again, re-entrance issues must be observed carefully in this case, at least for all calls accessing the same device.

5.3. Working with Very Low Count Rates

As noted above, the transfer block size is critical for efficient transfers. The larger the block size, the better the transfer efficiency. This is because setting up a transfer costs some fixed amount of time, independent of the block size. However, it may not under all circumstances be ideal to use the maximum size. A large block size takes longer to fill. If the count rates in your experiment are very low, it may be better to use a smaller block size. In this case the transfer function returns more promptly. It should be noted that the TimeHarp has a “watchdog” timer that terminates large transfer requests prematurely so that they do not wait forever if new data is coming very slowly. This results in `TH260_ReadFiFo` returning less than requested (possibly even zero). This helps to avoid complete stalls even if the maximum transfer size is used with low or zero count rates. However, for fine tuning of your application may still be of interest to use a smaller block size. The block size must be a multiple of 128 records. The smallest permitted size is 128.

Also note that with very low count rates (and sync rates) the hardware meters read out via `TH260_GetSyncRate` as well as `TH260_GetCountRate` are of limited precision. The hardware meters are using a hard wired count time window (gate) of 100 ms. Consequently, their resolution at the lower rate end is limited. If you must determine very slow sync rates you may want to use `TH260_GetSyncPeriod`. Note, however, that this routine does not average over multiple periods and may therefore deliver slightly more fluctuating results. If you need to determine very low count rates the only solution is to perform a measurement and count the actual measurement results.

5.4. Working with Warnings

The library provides routines for obtaining and interpreting warnings about critical measurement conditions. The mechanism and warning criteria are the same as those used in the regular TimeHarp software. In order to obtain and use these warnings also in your custom software you may want to use the library routine `TH260_GetWarnings`. This may help inexperienced users to notice possible mistakes before stating a measurement or even during the measurement.

It is important to note that the generation of warnings is dependent on the current count rates and the current measurement settings. It was decided that `TH260_GetWarnings` does not obtain the count rates on its own, because the corresponding calls take some time and might waste too much processing time. It is therefore necessary that `TH260_GetSyncRate` as well as `TH260_GetCountRate` (for all channels) have been called before `TH260_GetWarnings` is called. Since most interactive measurement software periodically retrieves the rates anyhow, this is not a serious complication.

The routine `TH260_GetWarnings` delivers the cumulated warnings in the form of a bit field. In order to translate this into readable information you can use `TH260_GetWarningsText`. Before passing the bit field into `TH260_GetWarningsText` you can mask out individual warnings by means of the bit masks defined in hhdefin.h.

5.5. Hardware Triggered Measurements

This measurement scheme works essentially like regular histogramming mode but it allows to start and stop the acquisition by means of external TTL signals. Since it is an advanced real-time technique, beginners are advised better not to use it. For the same reason, demos exist only in C.

Before using this scheme, consider when it is useful to do so. Remember that TTTR mode is usually the most efficient way of retrieving the maximum information on photon dynamics. By means of marker inputs the photon events can be precisely assigned to complex external event scenarios.

The TimeHarp's data acquisition can be controlled in various ways. Default is the TimeHarp's internal CTC (counter timer circuit). In that case the histograms will take the duration set by the `tacq` parameter passed to `TH260_StartMeas`. The other way of controlling the histogram boundaries (in time) is by external TTL signals fed to the control connector pins C1 and C2. In that case it is possible to have the acquisition started and stopped when specific signals occur. It is also possible to combine external starting with stopping through the internal CTC. The exact behaviour is controlled by the parameters supplied to the call of `TH260_SetMeasControl`. Dependent on the parameter `meascontrol` the following modes of operation can be obtained:

Symbolic Name	Value	Function
MEASCTRL_SINGLESHOT_CTC	0	Default value. Acquisition starts by software command and runs until CTC expires. The duration is set by the `tacq` parameter passed to `TH260_StartMeas.`
MEASCTRL_C1_GATE	1	Histograms are collected for the period where C1 is active. This can be the logical high or low period dependent on the value supplied to the parameter `startedge`.
MEASCTRL_C1_START_CTC_STOP	2	Data collection is started by a transition on C1 and stopped by expiration of the internal CTC. Which transition actually triggers the start is given by the value supplied to the parameter `startedge`. The duration is set by the `tacq` parameter passed to `TH260_StartMeas.`
MEASCTRL_C1_START_C2_STOP	3	Data collection is started by a transition on C1 and stopped by by a transition on C2. Which transitions actually trigger start and stop is given by the values supplied to the parameters `startedge` and `stopedge`.

The symbolic constants shown above are defined in `th260defin.h`. There are also symbolic constants for the parameters controlling the active edges (rising/falling).

Please study the demo code for external hardware triggering and observe the polling loops required to detect the beginning and end of a measurement. Be aware that the speed of you computer and the delays introduced by the operating system's task switching impose some limits on how fast you can run this scheme.

6. Problems, Tips & Tricks

6.1. PC Performance Issues

Performance issues with the DLL are the same as with the standard TimeHarp software. The TimeHarp device and its software interface are a complex real–time measurement system demanding appropriate performance both from the host PC and the operating system. This is why a fairly modern CPU and sufficient memory are required. At least a dual core, 1.5 GHz processor, 4 GB of memory and a fast hard disk are recommended. For high count rates and real-time data analysis a faster processor is always better.

6.2. PCIe Interface

In order to deliver maximum throughput, the TimeHarp 260 uses state–of–the–art busmastering DMA transfers. For this purpose it requires an interrupt line. Dependent on the design of the PC's mainboard there may be limited interrupt ressources so that slot cards and/or onboard devices need to share interrupt lines. This may lead to conflicts and/or performance degradation. Interrupt sharing can sometimes be avoided by using another slot. In some cases it is also possible to change interrupt assignments in the BIOS setup. In order to avoid trouble, please contact PicoQuant for advice on which PC or mainboard to buy.

6.3. Power Saving

If your computer is configured to allow power saving (suspend/sleep) then (dependent on BIOS configuration) the TimeHarp device may be powered down more or less unexpectedly. In order to avoid loss of data you may need to design your software so that it detetcs the corresponding power events (messages) sent by Windows, stop the current measurement and save the data. Upon wakeup you will need to repeat the initialization sequence of library calls to allow new measurements.

Another form of power saving that can cause complications is PCIe link power management (ASPM). There are Mainboards where ASPM is not implemented properly so that the TimeHarp 260 and other high speed PCIe cards will not work flawlessly. Some mainboard manufacturers such as ASUS provide BIOS updates that fix the issues. In cases where such updates are not available the workaround is to disable PCIe link power saving in the BIOS settings (if available) or in Windows via "advanced power plan settings".

6.4. Troubleshooting

Troubleshooting should begin by testing your hardware and driver setup. This is best accomplished by the standard TimeHarp software for Windows (supplied by PicoQuant). Only if this software is working properly you should start your work with the DLL. If there are problems even with the standard software, please consult the TimeHarp manual for detailed troubleshooting advice.

The DLL will access the TimeHarp device through a dedicated device driver. You need to make sure the device driver has been installed correctly. The driver is installed by standard software setup. Both the regular TimeHarp software distribution as well as the TH260Lib distribution media contain the driver. You can use the Windows Device Manager to check if the board has been detected and the driver is installed correctly. On some Windows installations you may need administrator rights to perform hardware setup tasks. Please consult the TimeHarp manual for hardware related problem solutions.

The next step, if hardware and driver are working, is to make sure you have the right DLL version installed. When the software setup was properly performed you should see start menu entries indicating the version of TH260Lib. In Windows Explorer you can also right click `TH260Lib64.DLL` and `TH260Lib.DLL` (in `\Windows\System32` or `\Windows\SysWOW64`) and check the version number (under *Properties*). You should also make sure your board has the right firmware with license to use the DLL. If the DLL license is missng you will get the error code -19 (TH260_ERROR_INVALID_OPTION).

To get started, ensure that your setup is working by running the regular TimeHarp software. In a next step try the readily compiled demos supplied with the DLL. For first tests take the standard histogramming demos. If this is working, your own programs should work as well. Note that the hard coded settings may not be compatible with your experimental setup. Then the pre–compiled demo may not work as expected. Only the LabVIEW demo allows to enter most of the settings interactively.

6.5. Access Permissions

In order to allow driver installation you will need administrator rights to perform the software setup. If the setup is performed by an administrator but used from other accounts without full access permission to all disk locations, these restricted accounts may no be able to run the demos in the default locations they have been installed to. In such cases it is recommended that you copy the demo directory or selected files from it to a dedicated development directory in which you have the necessary rights. Otherwise the administrator must give you full access to the demo directory. On some Windows versions it is possible to switch between user accounts without shutting down the running applications. It is not possible to start a TimeHarp program if any other program accessing the device is running in another user account that has been switched away. Doing so may cause crashes or loss of data.

6.6. Version Tracking

While PicoQuant will always try to maintain a maximum of continuity in further hardware and software development, changes for the benefit of technical progress cannot always be avoided. It may therefore happen, that data structures, calling conventions or program flow will change. In order to design programs that will recognize such changes with a minimum of trouble we strongly recommend that you make use of the functions provided for version retrieval of hardware and DLL. The demos show how to do this. In any case your software should issue a warning if it detects a library version other than that it was tested with.

6.7. Software Updates

We work hard to constantly improve and update the software for our instruments. This includes updates of the configurable hardware (FPGA). Such updates are important as they may affect reliability and interoperability with other products. The software updates are free of charge, unless major new functionality is added. It is strongly recommended that you check the picoquant web site for software updates.

6.8. Bug Reports and Support

The TimeHarp 260 TCSPC system has gone through extensive testing and several iterations of improvement. Nevertheless, it is a fairly new product and some glitches may still occur under the myriads of possible PC configurations and application circumstances. We therefore would like to offer you our support in any case of problems with the system. Do not hesitate to contact your sales representative or PicoQuant in case of difficulties with your TimeHarp or the programming library.

If you should observe errors or bugs caused by the TimeHarp system please try to find a reproducible error situation. Email a detailed description of the problem and all relevant circumstances, especially other hardware installed in your PC, to support@picoquant.com. Please run `msinfo32` to obtain a listing of your PC configuration and attach the summary file to your error report. Your feedback will help us to improve the product and documentation.

Of course we also appreciate good news: If you have obtained exciting results with one of our instruments, please let us know, and where appropriate, please mention the instrument in your publications. There is a reference publication[1] for the Timeharp 260 that you can simply cite without unduly endorsing a product.

At our Web–site we also maintain a large bibliography of publications related to our instruments. It may serve as a reference for you and other potential users. See http://www.picoquant.com/scientific/references/. Please submit your publications for addition to this list.

1 Wahl M., Rahn H.-J., Röhlicke T., Erdmann , R., Kell G., Ahlrichs, A., Kernbach, M., Schell, A.W., Benson, O.: Integrated Multichannel Photon Timing Instrument with Very Short Dead Time and High Throughput. *Review of Scientific Instruments*, 84, 043102 (2013)

7. Appendix

7.1. Data Types

The TimeHarp programming library TH260Lib.DLL is written in C and its data types correspond to standard C / C++ data types as follows:

char	8 bit, byte (or characters in ASCII)
short int	16 bit signed integer
unsigned short int	16 bit unsigned integer
int long int	32 bit signed integer
unsigned int unsigned long int	32 bit unsigned integer
__int64 long long int	64 bit signed integer
unsigned int64 unsigned long long int	64 bit unsigned integer
float	32 bit floating point number
double	64 bit floating point number

Note that the format for the decimal point may depend on your Windows settings at run–time of the TimeHarp software (usually national language dependent).

Note also that on platforms other than the x86 architecture byte swapping may occur when the TimeHarp data files are read there for further processing. We recommend using the native x86 architecture environment consistently.

The distribution pack includes a set of demo programs (source code) for various programming languages to show how access to TimeHarp data files can be implemented. They will be installed in the subfolder \Filedemo under the chosen installation folder.

7.2. Functions Exported by TH260Lib.DLL

See th260defin.h for predefined constants given in capital letters here. Return values < 0 denote errors. See errcodes.h for the error codes. On 32-bit platforms all functions must be called with _stdcall convention. On 64-bit platforms this defaults to the Microsoft x64 calling convention. Note, that TH260Lib is a multi device library with the capability to control more than one TimeHarp 260 simultaneously. For that reason all device specific functions (i.e. the functions from section 7.2.2 on) take a device index as first argument. The TimeHarp 260 may have one or two input channels. Note that functions taking a channel number as an argument expect the channels enumerated 0..N-1 while the interactive TimeHarp software as well as the connector labelling enumerates the channels 1..N. This is due to internal data structures and consistency with earlier products. Also note that there are different models of TimeHarp 260 boards and some of the library routines are specific to specific models. Furthermore, there are options (features) a given model may or may not have. You can retrieve the model information via TH260_GetHardwareInfo and the features via TH260_GetFeatures.

7.2.1. General Functions

These functions work independent from any device.

`int TH260_GetErrorString (char* errstring, int errcode);`

```
arguments:          errstring:      pointer to a buffer for at least 40 characters
                    errcode:        error code returned from a TH260_xxx function call

return value:       >0              success
                    <0              error
```

Note: This function is provided to obtain readable error strings that explain the cause of the error better than the numerical error code. Use these in error handling message boxes, support enquiries etc.

`int TH260_GetLibraryVersion (char* vers);`

```
arguments:          vers:           pointer to a buffer for at least 8 characters

return value:       =0              success
                    <0              error
```

Note: Use the version information to ensure compatibility of the library with your own application.

7.2.2. Device Specific Functions

All functions below are device specific and require a device index.

`int TH260_OpenDevice (int devidx, char* serial);`

```
arguments:          devidx:         device index 0..3
                    serial:         pointer to a buffer for at least 8 characters

return value:       =0              success
                    <0              error
```

Note: Opens the device for use. Must be called before any of the other functions below can be used.

`int TH260_CloseDevice (int devidx);`

```
arguments:          devidx:         device index 0..3

return value:       =0              success
                    <0              error
```

Note: Closes and releases the device for use by other programs.

`int TH260_Initialize (int devidx, int mode);`

```
arguments:          devidx:         device index 0..3
                    mode:           measurement mode
                                       0 = histogramming mode
                                       2 = T2 mode
                                       3 = T3 mode

return value:       =0              success
                    <0              error
```

Note: This routine must be called before any of the other routines below can be used. Note that some of them depend on the measurement mode you select here. See the TimeHarp manual for more information on the measurement modes.

7.2.3. Functions for Use on Initialized Devices

All functions below can only be used after `TH260_Initialize` was successfully called.

```
int TH260_GetHardwareInfo (int devidx, char* model, char* partno, char* version);

arguments:          devidx:          device index 0..3
                    model:           pointer to a buffer for at least 16 characters
                    partno:          pointer to a buffer for at least  8 characters
                    version:         pointer to a buffer for at least 16 characters

return value:       =0               success
                    <0               error
```

```
int TH260_GetSerialNumber (int devidx, char* serial);

arguments:          devidx:          device index 0..3
                    vers:            pointer to a buffer for at least 8 characters

return value:       =0               success
                    <0               error
```

```
int TH260_GetFeatures (int devidx, int* features);

arguments:          devidx:          device index 0..3
                    flags:           pointer to an integer
                                        returns features of this board (a bit pattern)

return value:       =0               success
                    <0               error
```

Note: Use the predefined bit feature values in `th260defin.h` (`FEATURE_xxx`) to extract individual bits through a bitwise AND. Typically this is only for information, or to check if your board has a specific (optional) capability.

```
int TH260_GetBaseResolution (int devidx, double* resolution, int* binsteps);

arguments:          devidx:          device index 0..3
                    resolution:      pointer to a double precision float (32 bit)
                                        returns the base resolution in ps
                    binsteps:        pointer to an integer,
                                        returns the maximally allowed binning steps

return value:       =0               success
                    <0               error
```

Note: The value returned in `binsteps` is the maximum value allowed for the TH260_SetBinning function.

```
int TH260_GetNumOfInputChannels (int devidx, int* nchannels);

arguments:          devidx:          device index 0..3
                    nchannels:       pointer to an integer,
                                        returns the number of installed input channels

return value:       =0               success
                    <0               error
```

Note: The number of input channels is counting only the regular detector channels. It does not count the sync channel. Nevertheless, it is possible to connect a detector also to the sync channel, e.g. in histogramming mode for antibunching or in T2 mode.

```
int TH260_SetTimingMode(int devidx, int mode);  // TimeHarp 260 P only

arguments:          devidx:         device index 0..3
                    mode:           0 = Hires (25ps), 1 = Lowres (2.5 ns, a.k.a. "Long range")
                                        will change the base resolution of the board

return value:       =0              success
                    <0              error
```

```
int TH260_SetSyncDiv (int devidx, int div);

arguments:          devidx:         device index 0..3
                    div:            sync rate divider
                                       (1, 2, 4, .., SYNCDIVMAX)

return value:       =0              success
                    <0              error
```

Note: The sync divider must be used to keep the effective sync rate at values < 40 MHz. It should only be used with sync sources of stable period. The readings obtained with TH260_GetCountRate are corrected for the divider setting and deliver the external (undivided) rate. When the sync input is used for a detector signal the divider should be set to 1.

```
int TH260_SetSyncCFD (int devidx, int level, int zerox);   // TimeHarp 260 P only

arguments:          devidx:         device index 0..3
                    level:          CFD discriminator level in millivolts
                                       minimum = CFDLVLMIN
                                       maximum = CFDLVLMAX
                    zerox:          CFD zero cross level in millivolts
                                       minimum = CFDZCMIN
                                       maximum = CFDZCMIN

return value:       =0              success
                    <0              error
```

```
int TH260_SetSyncEdgeTrg (int devidx, int level, int edge);   // TimeHarp 260 N only

arguments:          devidx:         device index 0..3
                    level:          Trigger level in millivolts
                                       minimum = CFDLVLMIN
                                       maximum = CFDLVLMAX
                    edge:           Trigger edge
                                       0 = falling
                                       1 = rising

return value:       =0              success
                    <0              error
```

Note: The actual effective trigger edge was wrong (inverted) up to version 3.1. This has been corrected in version 3.2.

```
int TH260_SetSyncChannelOffset (int devidx, int value);

arguments:          devidx:         device index 0..3
                    value:          sync timing offset in ps
                                       minimum = CHANOFFSMIN
                                       maximum = CHANOFFSMAX

return value:       =0              success
                    <0              error
```

```
int TH260_SetInputCFD (int devidx, int channel, int level, int zerox);   // TimeHarp 260 P only

arguments:          devidx:           device index 0..3
                    channel:          input channel index 0..1
                    level:            CFD discriminator level in millivolts
                                         minimum = CFDLVLMIN
                                         maximum = CFDLVLMAX
                    zerox:            CFD zero cross level in millivolts
                                         minimum = CFDZCMIN
                                         maximum = CFDZCMAX

return value:       =0                success
                    <0                error
```

Note: The maximum channel index must correspond to `nchannels-1` as obtained through TH260_GetNumOfInputChannels().

```
int TH260_SetInputEdgeTrg (int devidx, int channel, int level, int edge);   // TimeHarp 260 N only

arguments:          devidx:           device index 0..3
                    channel:          input channel index 0..1
                    level:            CFD discriminator level in millivolts
                                         minimum = DISCRMIN
                                         maximum = DISCRMAX
                    edge:             Trigger edge
                                         0 = falling
                                         1 = rising

return value:       =0                success
                    <0                error
```

Note: The maximum channel index must correspond to `nchannels-1` as obtained through TH260_GetNumOfInputChannels().
The actual effective trigger edge was wrong (inverted) up to version 3.1. This has been corrected in version 3.2.

```
int TH260_SetInputChannelOffset (int devidx, int channel, int value);

arguments:          devidx:           device index 0..3
                    channel:          input channel index 0..nchannels-1
                    value:            channel timing offset in ps
                                         minimum = CHANOFFSMIN
                                         maximum = CHANOFFSMAX

return value:       =0                success
                    <0                error
```

Note: The maximum channel index must correspond to `nchannels-1` as obtained through TH260_GetNumOfInputChannels().

```
int TH260_SetInputChannelEnable (int devidx, int channel, int enable);

arguments:          devidx:           device index 0..3
                    channel:          input channel index 0..nchannels-1
                    enable:           desired enable state of the input channel
                                         0 = disabled
                                         1 = enabled

return value:       =0                success
                    <0                error
```

Note: The maximum channel index must correspond to `nchannels-1` as obtained through TH260_GetNumOfInputChannels().

```
int TH260_SetInputDeadTime (int devidx, int channel, int tdcode); // TH260 P only

arguments:          devidx:           device index 0..3
                    channel:          input channel index 0..nchannels-1
                    tdcode:           code for desired deadtime of the input channel
                                         minimum = TDCODEMIN
                                         maximum = TDCODEMAX
```

```
return value:        =0              success
                     <0              error
```

Note: The maximum channel index must correspond to `nchannels-1` as obtained through TH260_GetNumOfInputChannels(). The codes 0..7 correspond to approximate deadtimes of 24, 44, 66, 88 112, 135, 160 and 180 ns. Exact values are subject to production tolerances on the order of 10%. This feature is not available in boards produced before April 2015 but can be upgraded on request. The main purpose is that of suppressing artefacts (afterpulsing) produced by some types of detectors. Whether or not a given board supports this feature can be checked via `TH260_GetFeatures` and the bit mask `FEATURE_PROG_TD` as defined in `thdefin.h`. Note that the programmable deadtime is not available for the sync input.

`int TH260_SetStopOverflow (int devidx, int stop_ovfl, unsigned int stopcount);`

```
arguments:           devidx:         device index 0..3
                     stop_ofl:       0 = do not stop,
                                     1 = do stop on overflow
                     stopcount:      count level at which should be stopped
                                        minimum = STOPCNTMIN
                                        maximum = STOPCNTMAX

return value:        =0              success
                     <0              error
```

Note: This setting determines if a measurement run will stop if any channel reaches the maximum set by `stopcount`. If `stop_ofl` is 0 the measurement will continue but counts above `STOPCNTMAX` in any bin will be clipped.

`int TH260_SetBinning (int devidx, int binning);`

```
arguments:           devidx:         device index 0..3
                     binning:        measurement binning code
                                        minimum = 0      (smallest, i.e. base resolution)
                                        maximum = (MAXBINSTEPS-1)              (largest)

return value:        =0              success
                     <0              error
```

Note: binning corresponds to repeated multiplication of the base resolution by 2 as follows:

0 = 1x base resolution,
1 = 2x base resolution,
2 = 4x base resolution,
3 = 8x base resolution, and so on.

`int TH260_SetOffset (int devidx, int offset);`

```
arguments:           devidx:         device index 0..3
                     offset:         histogram time offset in ns
                                        minimum = OFFSETMIN
                                        maximum = OFFSETMAX

return value:        =0              success
                     <0              error
```

Note: The offset programmed here is fundamentally different from the input offsets. It applies only **after** the time difference of input channel and sync has been calculated. It can be used to move arge stop-start differences into the histogram range that would normally not be recorded. It is only meaningful in histogramming and T3 mode.

`int TH260_SetHistoLen (int devidx, int lencode, int* actuallen);`

```
arguments:           devidx:         device index 0..3
                     lencode:        histogram length code
                                        minimum = 0
                                        maximum = MAXLENCODE    (default)
                     actuallen:      pointer to an integer,
                                        returns the current length (time bin count) of histograms
                                        calculated according to:  actuallen = 1024*(2^lencode)
```

```
return value:        =0              success
                     <0              error
```

Note: This sets the number of time bins in histogramming and T3 mode. It is not meaningful in T2 mode.

`int TH260_ClearHistMem (int devidx);`

```
arguments:           devidx:         device index 0..3
return value:        =0              success
                     <0              error
```

Note: This clears the histogram memory. It is not meaningful in T2 and T3 mode.

`int TH260_SetTriggerOutput (int devidx, int period);`

```
arguments:           devidx:         device index 0..3
                     period:         trigger period in units of 100ns  (0=off)
                                        minimum = TRIGOUTMIN
                                        maximum = TRIGOUTMAX
return value:        =0              success
                     <0              error
```

Note: This can be used to trigger external light sources. Use with caution when triggering lasers: Software can fail.

`int TH260_SetMeasControl (int devidx, int meascontrol, int startedge, int stopedge);`

```
arguments:           devidx:         device index 0..3
                     meascontrol:    measurement control code
                                        0 = MEASCTRL_SINGLESHOT_CTC
                                        1 = MEASCTRL_C1_GATED
                                        2 = MEASCTRL_C1_START_CTC_STOP
                                        3 = MEASCTRL_C1_START_C2_STOP
                     startedge:      edge selection code
                                        0 = falling
                                        1 = rising
                     stopedge:       edge selection code
                                        0 = falling
                                        1 = rising
return value:        =0              success
                     <0              error
```

Note: This is a very specialized routine for externally (hardware) controlled measurements. Normally it is not needed. See section 5.5 for details.

`int TH260_StartMeas (int devidx, int tacq);`

```
arguments:           devidx:         device index 0..3
                     tacq:           acquisition time in milliseconds
                                        minimum = ACQTMIN
                                        maximum = ACQTMAX
return value:        =0              success
                     <0              error
```

Note: This starts a measurement in the current measurement mode. Should be called after all settings are done. Previous measurements should be stopped before calling this routine again.

`int TH260_StopMeas (int devidx);`

```
arguments:           devidx:         device index 0..3
```

```
return value:        =0                success
                     <0                error
```

Note: This **must** be called after the acquisition time is expired. Can also be used to force stop before the acquisition time expires.

`int TH260_CTCStatus (int devidx, int* ctcstatus);`

```
arguments:           devidx:           device index 0..3
                     ctcstatus         pointer to an integer,
                                          returns the acquisition time state
                                          0 = acquisition running
                                          1 = acquisition has ended
return value:        =0                success
                     <0                error
```

Note: This routine should be called to determine if the acuisition time has expired.

`int TH260_GetHistogram (int devidx, unsigned int *chcount, int channel, int clear);`

```
arguments:           devidx:           device index 0..3
                     chcount           pointer to an array of at least actuallen double words (32bit)
                                          where the histogram data can be stored
                     channel:          input channel index 0..nchannels-1
                     clear             denotes the action upon completing the reading process
                                          0 = keeps the histogram in the acquisition buffer
                                          1 = clears the acquisition buffer
return value:        =0                success
                     <0                error
```

Note: The histogram buffer size `actuallen` must correspond to the value obtained through TH260_SetHistoLen().
The maximum input channel index must correspond to `nchannels-1` as obtained through TH260_GetNumOfInputChannels().

`int TH260_GetResolution (int devidx, double* resolution);`

```
arguments:           devidx:           device index 0..3
                     resolution:       pointer to a double precision float (64 bit)
                                          returns the resolution at the current binning
                                          (histogram bin width) in ps
return value:        =0                success
                     <0                error
```

Note: This is meaningful only in histogramming and T3 mode. T2 mode always runs at the boards's base resolution.

`int TH260_GetSyncRate (int devidx, int* syncrate);`

```
arguments:           devidx:           device index 0..3
                     syncrate:         pointer to an integer
                                          returns the current sync rate
return value:        =0                success
                     <0                error
```

Note: This is used to get the pulse rate at the sync input. The result is internally corrected for the current sync divider setting.
Allow at least 100 ms after TH260_Initialize or TH260_SetSyncDivider to get a stable rate reading. Similarly,
wait at least 100 ms to get a new reading. This is the gate time of the hardware counters.

int TH260_GetCountRate (int devidx, int channel, int* cntrate);

```
arguments:          devidx:          device index 0..3
                    channel:         number of the input channel 0..nchannels-1
                    cntrate:         pointer to an integer
                                        returns the current count rate of this input channel

return value:       =0               success
                    <0               error
```

Note: Allow at least 100 ms after TH260_Initialize to get a stable rate reading. Similarly, wait at least 100 ms to get a new reading. This is the gate time of the hardware counters. The maximum channel index must correspond to `nchannels-1` as obtained through TH260_GetNumOfInputChannels().

int TH260_GetFlags (int devidx, int* flags);

```
arguments:          devidx:          device index 0..3
                    flags:           pointer to an integer
                                        returns current status flags (a bit pattern)

return value:       =0               success
                    <0               error
```

Note: Use the predefined bit mask values in th260defin.h (e.g. FLAG_OVERFLOW) to extract individual bits through a bitwise AND.

int TH260_GetElapsedMeasTime (int devidx, double* elapsed);

```
arguments:          devidx:          device index 0..3
                    elapsed:         pointer to a double precision float (64 bit)
                                        returns the elapsed measurement time in ms

return value:       =0               success
                    <0               error
```

Note: During a measurememt this can be called to obtain the measurement time that has elapsed so far. After a measurement it will return the time that actually elapsed before the measurement was stopped (e.g. due to histogram overflow or forced stop).

int TH260_GetWarnings (int devidx, int* warnings);

```
arguments:          devidx:          device index 0..3
                    *warnings:       pointer to integer bitfield receiving the warnings

return value:       =0               success
                    <0               error
```

Note: You must call TH260_GetCoutRate and TH260_GetCoutRate for all channels prior to this call.

int TH260_GetWarningsText (int devidx, char* text, int warnings);

```
arguments:          devidx:          device index 0..3
                    text:            pointer to a buffer for at least 16384 characters
                    warnings:        integer bitfield obtained from TH260_GetWarnings

return value:       =0               success
                    <0               error
```

Note: This helps to identify suspicious measurement conditions that may be due to inappropriate settings.

int TH260_GetHardwareDebugInfo (int devidx, char* text);

```
arguments:          devidx:          device index 0..3
                    text:            pointer to a buffer for at least 16384 characters
```

```
return value:        =0              success
                     <0              error
```

note: Call this routine if you receive the error code TH260_ERROR_STATUS_FAIL or the flag FLAG_SYSERROR. See th260defin.h and errorcodes.h for the numerical values of these codes. Provide the result for support.

`int TH260_GetSyncPeriod(int devidx, double* period);`

```
arguments:           devidx:         device index 0..3
                     period:         pointer to a double precision float (64 bit)
                                        returns the sync period in seconds

return value:        =0              success
                     <0              error
```

note: As opposed to GetSyncRate this does not integrate over multiple periods. The period value is only useful in applications with periodic sync signals. In case of very long periods it takes a correspondingly long time to get a meaningful result. This time is increased to n-fold if a sync divider n is set.

7.2.4. Special Functions for TTTR Mode

Note: TTTR mode is supported by all TimeHarp 260 models but markers are supported only by the DUAL models.

`int TH260_ReadFiFo (int devidx, unsigned int* buffer, int count, int* nactual);`

```
arguments:           devidx:         device index 0..3
                     buffer:         pointer to an array of count double words (32bit)
                                        where the TTTR data can be stored
                     count:          number of TTTR records the buffer can hold
                                        (min = TTREADMIN, max = TTREADMAX)
                     nactual:        pointer to an integer
                                        returns the number of TTTR records received

return value:        =0              success
                     <0              error
```

Note: CPU time during wait for completion will be yielded to other processes / threads. The call will return after a timeout period of a few ms if no more data could be fetched. The buffer must not be accessed until the call returns.
Note that the buffer should be aligned on a 4096-byte boundary in order to allow efficient DMA transfers.
If the buffer does not meet this requirement the library will use an internal buffer and copy the data. This slows down data throughput.

`int TH260_SetMarkerEdges (int devidx, int me0, int me1, int me2, int me3);`

```
arguments:           devidx:         device index 0..3
                     me<n>:          active edge of marker signal <n>,
                                        0 = falling,
                                        1 = rising

return value:        =0              success
                     <0              error
```

`int TH260_SetMarkerEnable (int devidx, int en0, int en1, int en2, int en3);`

```
arguments:           devidx:         device index 0..3
                     en<n>:          desired enable state of marker signal <n>,
                                        0 = disabled,
                                        1 = enabled

return value:        =0              success
                     <0              error
```

```
int TH260_SetMarkerHoldoffTime (int devidx, int holdofftime);

arguments:          devidx:           device index 0..3
                    en<n>:            desired holdoff time for marker signals in nanoseconds
                                         min = 0,
                                         max = 25500

return value:       =0                success
                    <0                error
```

Note: After receiving a marker the system will suppress subsequent markers for the duration of `holdofftime` (ns). This can be used to suppress glitches on the marker signals. This is only a workaround for poor signals. Try to solve the problem at its origin, i.e. the quality of marker source and cabling.

7.3. Warnings

The following is related to the warnings (possibly) generated by the library routine `TH260_GetWarnings`. The mechanism and warning criteria are the same as those used in the regular TimeHarp software and depend on the current count rates and the current measurement settings.

Note that the software can detect only a subset of all possible error conditions. It is therefore not safe to assume "all is right" just by obtaining no warning. It is also necessary that `TH260_GetCoutrate` has been called for all channels before `TH260_GetWarnings` is called.

The warnings are to some extent dependent on the current measurement mode. Not all warnings will occur in all measurement modes. Also, count rate limits for a specific warning may be different in different modes. The following table lists the possible warnings in the three measurement modes and gives some explanation as to their possible cause and possible consequences.

Warning	Histo Mode	T2 Mode	T3 Mode
WARNING_SYNC_RATE_ZERO No pulses are detected at the sync input. In histogramming and T3 mode this is crucial and the measurement will not work without this signal.	√		√
WARNING_SYNC_RATE_VERY_LOW The detected pulse rate at the sync input is below 100 Hz and cannot be determined accurately. Other warnings may not be reliable under this condition.	√		√
WARNING_SYNC_RATE_TOO_HIGH The pulse rate at the sync input (after the divider) is higher than 40 MHz. Sync events will be lost in dead time. T2 mode is normally intended to be used without a fast sync signal and without a divider. If you see this warning in T2 mode you may accidentally have connected a fast laser sync.	√	√	√
WARNING_INPT_RATE_ZERO No counts are detected at any of the input channels. In histogramming and T3 mode these are the photon event channels and the measurement will yield nothing. You might sporadically see this warning if your detector has a very low dark count rate and is blocked by a shutter. In that case you may want to disable this warning.	√	√	√
WARNING_INPT_RATE_TOO_HIGH The overall pulse rate at the input channels is higher than 40 MHz. The measurement will inevitably lead to a FiFo overrun. There are some rare measurement scenarios where this condition is expected and the warning can be disabled. Examples are measurements where the FiFo can absorb all data of interest before it overflows.	√	√	√

Warning	Histo Mode	T2 Mode	T3 Mode
WARNING_INPT_RATE_RATIO This warning is issued in histogramming and T3 mode when the rate at any input channel is higher than 5% of the sync rate. This is the classical pile-up criterion. It will lead to noticeable dead-time artefacts. There are rare measurement scenarios where this condition is expected and the warning can be disabled. Examples are antibunching measurements.	√		√
WARNING_DIVIDER_GREATER_ONE In T2 mode: The sync divider is set larger than 1. This is probably not intended. The sync divider is designed primarily for high sync rates from lasers and requires a fixed pulse rate at the sync input. In that case you should use T3 mode. If the signal at the sync input is from a photon detector (coincidence correlation etc.) a divider > 1 will lead to unexpected results. There are rare measurement scenarios where this condition is intentional and the warning can be disabled. In histogramming and T3 mode: The pulse rate at the sync input is below 40 MHz and the Sync-Divider >1 is not needed. The measurement may yield unnecessary jitter if the sync source is not very stable.	√	√	√
WARNING_DIVIDER_TOO_SMALL The pulse rate at the sync input (after the divider) is higher than 40 MHz and Sync events will be lost in dead time. Increase the sync divider.	√		√
WARNING_TIME_SPAN_TOO_SMALL This warning is issued in histogramming and T3 mode when the sync period (1/SyncRate) is longer than the start to stop time span that can be covered by the histogram or by the T3 mode records. You can calculate this time span as follows: Span = Resolution * 32768 Events outside this span will not be recorded. There are some measurement scenarios where this condition is intentional and the warning can be disabled.	√		√
WARNING_OFFSET_UNNECESSARY This warning is issued in histogramming and T3 mode when an offset >0 is set even though the sync period (1/SyncRate) can be covered by the measurement time span without using an offset. The offset may lead to events getting discarded. There are some measurement scenarios where this condition is intentional and the warning can be disabled.	√		√
WARNING_COUNTS_DROPPED This warning is issued when the front end of the data procesing pipeline was not able to process all events that came in. This will occur typically only at very high count rates during intense bursts of events.	√	√	√

If any of the warnings you receive indicate wrong pulse rates, the cause may be inappropriate input settings, wrong pulse polarities, slow rise times, poor pulse shapes or bad connections. If in doubt, check all signals

with an oscilloscope of sufficient bandwidth and 50 Ohms input impedance. Note: you must not connect an oscilloscope with 50 Ohms input in parallel via simple T-connector. If you really need to use the oscilloscope in parallel with the regular signal sink then you need to use a reflection-free T-pad, which, however, reduces the signal amplitude.

All information given in this manual is reliable to our best knowledge. However, no responsibility is assumed for possible inaccuracies or omissions. Specifications and external appearance are subject to change without notice.

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