PicoHarp 300

Picosecond Histogram
Accumulating Real-time Processor

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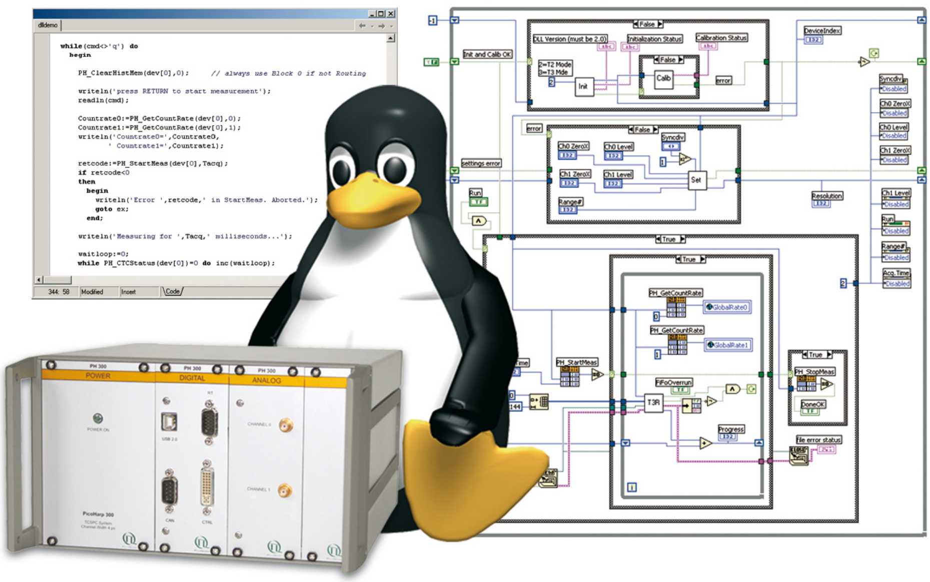
PHLib.so Programming Library for Custom Software Development under Linux



User's Manual

Version 2.2 - November 2007

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1. Introduction

The PicoHarp 300 is a compact and easy-to-use TCSPC system with USB interface. Its new design enhances functionality, keeps cost down, improves reliability and simplifies calibration. The timing circuit allows high measurement rates up to 10 Mcounts/s and provides a time resolution of 4 ps. The input channels are programmable for a wide range of input signals. They both have programmable Constant Fraction Discriminators (CFD). These specifications qualify the PicoHarp 300 for use with all common single photon detectors such as Single Photon Avalanche Photodiodes (SPAD), Photo Multiplier Tubes (PMT) and MCP-PMT modules (PMT and MCP-PMT via preamp). The time resolution is well matched to fast detectors and the overall Instrument Response Function (IRF) will not be limited by the PicoHarp electronics. Similarly inexpensive and easy-to-use diode lasers such as the PDL 800-B with interchangeable laser heads can be used as an excitation source perfectly matched to the time resolution offered by the detector and the electronics. Overall IRF widths of 200 ps FWHM can be achieved with inexpensive PMTs and diode lasers. Down to 50 ps can be achieved with selected diode lasers and MCP-PMT detectors. 30 ps can be reached with femtosecond lasers. This permits lifetime measurements down to a few picoseconds with deconvolution e.g. via the FluoFit multiexponential Fluorescence Decay Fit Software. For more information on the PicoHarp 300 hardware and software please consult the PicoHarp 300 manual. For details on the method of Time-Correlated Single Photon Counting, please refer to our TechNote on TCSPC.

The PicoHarp 300 standard software for Windows 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 PicoHarp'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 this approach may be of interest. For this purpose a programming library is provided as a Dynamic Link Library (DLL) for Windows. As an alternative, a Linux version of the library is offered, which is subject of this manual. It is 100% API compatible with the Windows library, so that applications can be ported very easily.

The 32 bit shared library 'PHLib.so' supports custom programming under Linux in all major programming languages, notably C/C++, Pascal, MATLAB and LabVIEW. This manual describes the installation and use of the PicoHarp programming library PHLib.so and explains the associated demo programs. Please read both this manual and the PicoHarp manual before beginning your own software developement with the library. The PicoHarp 300 is a sophisticated real-time measurement system. In order to work with the system using the library, sound knowledge in your chosen programming language is required.

2. General Notes

This version of the PicoHarp 300 programming library is suitable for Linux versions 2.6.x running on the x86 32 bit platform. It uses Libusb so that no kernel driver is required. Note that the library is provided as a binary object only.

This manual assumes that you have read the PicoHarp 300 manual and that you have experience with the chosen programming language. References to the PicoHarp manual will be made where necessary.

This version of the library supports histogramming mode and both TTTR modes but TTTR mode is only usable if the TTTR option was purchased and installed in the device firmare memory.

Users who purchased a license for any older version of the library will receive free updates when they are available. For this purpose, please register by sending email to *info@picoquant.com* with your name, your PicoHarp 300 serial number and the email address you wish to have the update information sent to.

Users upgrading from earlier versions of the PicoHarp 300 library or moving over from the Windows DLL need to adapt their programs. Some changes are usually necessary to accommodate new measurement modes and improvements. However, the required changes are mostly minimal and will be explained in the manual (especially check section 6, 7 and the notes marked red in section 10).

Note that despite of our efforts to keep changes minimal, data structures, program flow and function calls may still 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 10). Similarly, the development of Linux is highly dynamic and distributions may vary considerably. This manual can therefore only try and describe a snapshot valid at the time of writing.

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With this product you have purchased a license to use the PicoHarp 300 programming library on a single PC. 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.

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PHLib.so dynamically links with Libusb.so to acces the PicoHarp USB device. Libusb for Linux is licensed under the LGPL which allows a fairly free use even in commercial projects. For details and precise terms please see http://libusb.sourceforge.net/.

3. Firmware Update

Note: You can skip this section if you bought your PicoHarp with the DLL option readily installed.

The PicoHarp 300 programming library requires a firmware update of your PicoHarp 300, unless you already bought it with the DLL option installed. The update must be performed by DLLUPD.EXE under Windows. This file is provided to you (typically be email) only if you purchased an upgrade for the DLL option. It is compiled specifically for the serial number of your PicoHarp and cannot be used on others. The firmware update only needs to be done once. If necessary, perform the following steps to install the update:

(see your PicoHarp manual for steps 1..3 listed below)

1. Make sure your PicoHarp 300 is powered and connected correctly through USB 2.0.
2. Check that the standard PicoHarp 300 software for Windows runs correctly.
3. Make sure to exit the PicoHarp 300 software.
4. Start the program DLLUPD.EXE from a temporary disk location.
5. Follow the instructions. Do not interrupt the actual update progress, it may take a minute or so. The program will report successful completion.

After successful completion of the upgrade your PicoHarp is ready to use PHLib. See the sections below for hints how to install and use it.

4. Installation of the PHLib Software Package

4.1 Requirements

Supported hardware is at this time the x86 platform (32 bits) only. Recommended is a PC with at least 1 GHz CPU clock and 512 MB of memory. For serious use of the TTTR measurement modes a modern hard disk with DMA enabled is required (see *man hdparm* to check DMA settings).

The PicoHarp 300 library is designed to run on Linx kernel version 2.6. It has been tested with the following Linux distributions:

SuSE Linux 9.1, 9.3, 10.1, 10.2 and 10.3
Fedora Core 6 and Fedora 7
Kubuntu 6.10, 7.04 and 7.10
Debian 4.0
Scientific Linux 4.4

Using the PicoHarp 300 library requires libusb (see http://libusb.sourceforge.net/). It is part of all recent Linux distributions and should be installed on your system. The recommended version we have tested is 0.1.12.

It is recommended to start your work with the PicoHarp 300 by using the standard interactive PicoHarp data acquisition software under Windows. This should give you a better understanding of the instrument's operation before attempting your own programming efforts. It also ensures that your optical/electrical setup is working. If you are planning to use a router, try to get everything working without router first to avoid additional complications.

4.2 Libusb Access Permissions

For device access through libusb, your kernel needs support for the USB filesystem (usbfs) and that filesystem must be mounted. This is done automatically, if /etc/fstab contains a line like this:

```
usbfs /proc/bus/usb usbfs defaults  0  0
```

This should routinely be the case if you installed any of the tested distributions.
The permissions for the device files used by libusb must be adjusted for user access. Otherwise only root can use the device(s). The device files are located in /proc/bus/usb/. Any manual change would not be permanent, however. The permissions will be reset after reboot or replugging the device. A much more elegant way of finding the right files and setting the suitable permissions is by means of hotplugging scripts or udev. Which mechanism you can use depends on the Linux distribution you have. While the hotplug package was standard until recently, newer distributions starting from Fedora Core 5, Kubuntu 6.10 and SuSe 10.1 replace hotplug with udev.

Hotplug

For automated setting of the device file permissions with hotplug you have to add an entry to the hotplug “usermaps”. These files are located in /etc/hotplug/. If the entire hotplug directory does not exist, you probably don't have the hotplug package installed. This may be because your distribution is rather old (you may still be able to install hotplug) or it is very new and uses udev instead of hotplug (see section below).

Every line in the hotplug usermap files is for one device, the line starts with a name that will also be used for a handler script. Here we are trying to get a PicoHarp300 device working, so let's call the entry "PicoHarp300". The next entry is always 0x0003. The following two entries are the vendor ID (0x0e0d for PicoQuant) and the product ID (0x0003 for the PicoHarp 300). The remaining fields are all set to 0.

The line for the PicoHarp should look like below. The whole string should be on one line. Here it only wraps around due to limited page width:

```
PicoHarp300     0x0003     0x0e0d  0x00003   0x0000     0x0000
            0x00       0x00         0x00         0x00         0x00            0x00       0x00000000
```

The handler script “PicoHarp300” gets started when the device is connected or disconnected. It looks like this:

```
#!/bin/bash

if [ "${ACTION}" = "add" ] && [ -f "${DEVICE}" ]
then
      chown root "${DEVICE}"
      chgrp users "${DEVICE}"
      chmod 666 "${DEVICE}"
fi
```

When the PicoHarp gets switched on or connected, the hotplug system will recognize it and will run the script, which will then change the permissions on the device file associated with the device to 666, which means that everybody can both read and write from/to this device. Note that this may be regarded as a security gap. If you whish tighter access control you can create a dedicated group for PicoHarp users and give access only to that group.

Both a usemap file *PicoHarp300.usermap* and the handler script *PicoHarp300* are provided in the hotplug folder on the PHLib distribution media. Copying both of them to /etc/hotplug/usb/ should be sufficient to set up acces conrol via hotplugging for your PicoHarp.

Udev

As noted above, recent distributions such as Fedora Core 5 & SuSe 10.1 and later replace hotplug with udev. You won't find /etc/hotplug in this case. Instead, you can use udev to create the devices so they are readable and writable by non-priveleged users. The udev rules are contained in files in /etc/udev/rules.d. Udev processes these files in alphabetical order. The default file is usually called 50-udev.rules. Don't change this file as it could be overwritten when you upgrade udev. Instead, write your custom rule for the PicoHarp in a separate file. The contents of this file for the handling of the PicoHarp 300 should be:

```
SYSFS{idVendor}=="0d0e", SYSFS{idProduct}=="0003", MODE="0666"
```

A suitable rules file *PicoHarp.rules* is provided in the udev folder on the PHLib distribution media. You can simply copy it to the rules.d folder. The install script in the same folder does just this. Note that the name of the rules file is important. Each time a device is detected by the hotplug system, the files are read in alphabetical order, line by line, until a match is found. Note that different distributions may use different rule file names for various categories. For instance, Kubuntu organizes the rules into further files: 20-names.rules, 40-permissions.rules, and 60-symlinks.rules. In Fedora they are not separated by those categories, as you can see by studying 50-udev.rules. Instead of editing the existing files, it is therefore usually recommended to put all of your modifications in a separate file like 10-udev.rules or 10-local.rules. The low number at the beginning of the file name ensures it will be processed before the default file. However, later rules that are more general (applying to a whole class of devices) may later override the desired acecss rights. This is the case for USB devices handled through Libusb. It is therefore important that you use a rules file for the PicoHarp that gets evaluated after the general case. The default naming “PicoHarp300.rules” most likely ensures this.

Note that there are different udev implementations with different command sets. On some distributions you must reboot to activate changes, on others you can reload rule changes and restart udev with these commands:

```
# udevcontrol reload_rules
# udevstart
```

4.3 Installing the Library

The library is distributed as a binary file. By default it resides under */usr/local/lib/ph300*. This is not a strict requirement but it is where the demo programs will look for the library files and therefore it is recommended to use this location. You can create the directory */usr/local/lib/ph300* and copy all files from the directory *library* on the distribution media to */usr/local/lib/ph300* (p*hlib.so, phlib.h, phdefin.h* and *errorcodes.h*). The shell script *install* in the *library* distribution directory does the directory creation and installation in one step. As root, just issue it at the command prompt from within the *library* directory. After installing, the library is ready to use and can be tested with the demos provided. If you want to install the library in a different place and/or if you want to simplify access to the library you can add the chosen path to */etc/ld.so.conf* and/or to the path list in the environment variable *LD_LIBRARY_PATH*.

Note for SELinux: If upon linking with phlib.so you get an error *“cannot restore segment prot after reloc”* you need to adjust the security settings for phlib.so. As root you need to run:

```
chcon -t texrel_shlib_t /usr/local/lib/ph300/phlib.so
```

4.4 Installing the Demo Programs

The demos can be installed by simply copying the entire directory *demos* from the distribution media to a disk location of your choice. This need not be under the root account but you need to ensure proper file permissions. While the C compiler for the C demos is part of all linux distributions, you will need to obtain and install Kylix, Matlab or LabVIEW for Linux separately if you wish to use these programming environments.

5. New in this Version

PHLib version 2.2 is primarily a bugfix release. Corrected were notably crosstalk issues with routing devices.

Note that from PHLib version 2.0 multiple PicoHarp devices can be controlled through the library. Up to PHLib version 1.2 only one PicoHarp device was supported. This change required the introduction of new functions for open/close and a device index for every library call. Users upgrading from earlier versions of the PHLib therefore need to adapt their programs. It is important to note here one more time that you must maintain appropriate version checking in order to avoid crashes or malfunction due to such changes. There is a function call tat you can use to retrieve the version number (see section 10). The changes from 1.2 to 2.x are also marked red in section 10.

6. The Demo Applications - 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. For any practical work the demo programs will almost always require modification.

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 purely text based from a shell prompt (terminal window). For the same reason, the measurement parameters are mostly hard-coded and thereby fixed at compile time. It may therefore be 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 may 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 PicoHarp 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, Kylix, LabVIEW and MATLAB. The demos are 99% identical to those for Windows, so that code can easily be ported between the platforms. For each of the programming languages/systems there are different demo versions for various measurement modes:

Standard Mode Demos

These demos show how to use the standard measurement mode for on-board histogramming. These are the simplest demos and the best starting point for your own experiments. In case of LabVIEW the standard mode demo is already fairly sophisticated and allows interactive input of most parameters. The standard mode demos will not initialize or use a router that may be present. Please do not connect a router for these demos.

Routing Demos

Multi channel measurement (routing) is possible in standard histogramming mode and in TTTR mode. It requires that a PHR 40x or PHR 800 router and multiple detectors are connected. The routing demos show how to perform such measurements in histogramming mode and how to access the histogram data of the individual detector channels. The concept of routing in histogramming mode is quite simple and similar to standard histogramming. In TTTR mode it is also very simple using the same library routines. Therefore, no dedicated demo is provided for routing in TTTR mode. To get started see the section about routing in your PicoHarp 300 manual. If you need the routing functionality in any of the other demos you need to copy the relevant code fragments from the routing demos.

TTTR Mode Demos

These demos show how to use TTTR mode, i.e. recording individual photon events instead of forming histograms on board. This permits extremely sophisticated data analysis methods, such as single molecule burst detection, the combination of fluorescence lifetime measurement with FCS, and picosecond coincidence correlation.

The PicoHarp 300 actually supports two different Time-Tagging modes, T2 and T3 Mode. When referring to both modes together we use the general term TTTR here. For details on the two modes, please refer to your PicoHarp manual. TTTR mode always implicitly performs routing if a router and multiple detectors are used. It is also possible to record external TTL signal transitions as markers in the TTTR data stream e.g. for image scanning applications (see the PicoHarp manual).

Note: TTTR mode is not part of the standard PicoHarp product. It must be purchased as a separate firmware option that gets burned into the ROM of the device. An upgrade is possible at any time. It always includes both T2 and T3 mode.

Because TTTR mode requires real-time processing and/or real-time storing of data, the TTTR demos are fairly demanding both in programming skills and computer performance. See the section about TTTR mode in your PicoHarp manual as well as section 8 here.

7. The Demo Applications by Programming Language

As outlined above, there are demos for C, Kylix, 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 PicoHarp 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 PicoHarp library as your first attempt at programming. Please study the documentation of your chosen programming language, especially on how to call routines in dynamic link libraries. The ultimate reference for details about how to use the library is in any case the source code of the demos and the header files of PHlib (*phlib.h, phdefin.h* and *errorcodes.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. Make sure to backup your data and/or perform your development work on a dedicated machine that does not contain valuable data. Note that the library is not re-entrant. This means, it cannot be accessed from multiple, concurrent processes or threads at the same time. All calls must be made sequentially in the order shown in the demos.

The C/C++ Demos

The demos are provided in the 'C' subfolder. The code is in plain C to provide the smallest common denominator for C and C++. Consult *phlib.h*, *phdefin.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 "phdefin.h"
#include "phlib.h"
}
```

To test any of the demos, consult the PicoHarp manual for setting up your PicoHarp 300 and establish a measurement setup that runs correctly and generates useable test data. Compare the settings (notably sync divider, range and CFD levels) with those used in the demo and use the values that work in your setup when building and testing the demos.

All C demos can be compiled with gcc. They come with a makefile so that a simple call of make in the respective source folder should readily build the application. PHlib and Libusb are linked dynamically.

The C demos are designed to run purely text based in a console (terminal window). 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 standard histogramming demos. 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. 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 PicoHarp 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 PHLib 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 PH_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.

The Kylix Demos

Borland Kylix is a rapid application development system for Linux based on the Pascal language, like Delphi for Windows. The Kylix/Delphi pair allows to develop cross-platform portable programs for Linux and Windows. Kylix users please refer to the *kylix* branch of the *demo* directory. Everything for the respective demo is in the project file for that demo (*.DPR). In order to make the exports of the library 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. The supplied executables were compiled with Kylix 3 Professional. In order to modify and rebuild them for your own non-commercail purposes you can also use the free Open Edition of Kylix. Note that (at the time of this writing) unfortunately Kylix 3 does not run on the most recent Linux distributions. An alternative is the free Lazarus project.

The Kylix demos are also designed to run purely text based in a console (terminal window). 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 standard 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 PicoHarp 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 PHLib 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 PH_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 'LABVIEW' directory. They are contained in LabVIEW libraries (*.llb). The top level VI is always 'PicoHarp.vi'. Note that the sub-VIs in the various demos are not always identical, even though their names may be the same. We have tested and saved the VIs with LabVIEW 6.1 for Linux. Newer versions will probably work but have not been tested.

The LabVIEW demos are the most sophisticated demos here. The standard mode demo to some extent resembles the standard PicoHarp software with input fields for all settable parameters. Run the toplevel VI PicoHarp.vi. It will first initialize and calibrate the hardware. The status of initialization and calibration will be shown in the top left display area. Make sure you have a running TCSPC setup with sync and detector correctly connected. You can then adjust the sync level until you see the expected sync rate in the meter below. Then you can click the *Run* button below the histogram display area. The demo implements a simple *Oscilloscope mode* of the PicoHarp. Make sure to set an acquisition time of not much more than e.g. a second, otherwise you will see nothing for a long time. If the input discriminator settings are correct you should see a histogram. You can stop the measurement with the same (*Run)* button.

The TTTR mode demo for LabVIEW is a little simpler. It provides the same panel elements for setting parameters etc. but there is no graphic display of results. Instead, all data is stored directly to disk. 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 to the Initialization VI to a value of 3 if you want T3 mode. You also need to use an appropriate sync divider and a suitable range (resolution).

To run the TTTR mode demo you start PicoHarp.vi. First set up the Sync and CFD levels. You can watch the sync rate in a graphic rate meter. Then you can select a measurement time and a file name. Make sure this is on a path you have suitable permissions for. When you click the *Run* button a measurement will be performed, with the data going directly to disk. There is a status indicator showing the current number of counts recorded. There is also a status LED indicating any FiFo overrun.

Internally the TTTR mode demo also deserves a special note: each TTTR record as returned in the buffer of PH_TTReadData actually is a DWORD (32bit). However, LabVIEW stores DWORD data (U32) always in big endian format. On the x86 platform (little endian) this results in reversed bytes compared to C programs. For consistency with the demo programs for reading TTTR data this byte reversing of the data going to disk is avoided in the demo by declaring the buffer for PH_TTReadData as a byte array (hence 4 times longer than the DWORD array). You may instead want to work with a

U32 array if your goal is not storing data to disk but doing some on-line analysis of the TTTR records. In this case you must initialize the array with 65536 x U32 and change the type of buffer in the library calls of PH_TTReadData to U32.

The LabVIEW demos access the library routines via the 'Call Library Function' of LabVIEW. For details refer to the LabVIEW documentation. Consult phlib.h and section 10 of this manual for the parameter types etc.

Strictly observe that the PH_xxxx library calls are not re-entrant. They must be made sequentially and in the right order. They cannot be called in parallel as is the default in LabVIEW if you place them side by side in a diagram. Although you can configure each library call to avoid parallel execution, this still gives no precise control over the order of execution. For some of the calls this order is very important. Sequential execution must therefore be enforced by sequence structures or data dependency. In the demos this is e.g. done by chained and/or nested case structures. This applies to all VI hierarchy levels, so sub-VIs containing library calls must also be executed in correct sequence.

The MATLAB Demos

The MATLAB demos are provided in the 'MATLAB' directory. They are contained in m-files. You need to have a MATLAB version that supports the 'calllib' function. We have tested with MATLAB 7.3 but any version from 6.5 should work. Be very careful about the header file name specified in 'loadlibrary'. This name is 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 files will be ASCII in case of the standard histogramming demo and in case of the routing 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 PicoHarp 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 PHLib 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 PH_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).

8. Advanced Techniques

Using Multiple Devices

Starting from version 2.0 the library is designed to work with multiple PicoHarp devices (up to 8). The demos always use the first device found. If you have more than one PicoHarp and you want to use them together you need to modify the code accordingly. At the API level of PHLib the devices are distinguished by a device index (0..7). The device order corresponds to the order Libusb enumerates the devices. This can be somewhat unpredictable. 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 PH_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 PH_GetSerialNumber any time later on a device you have successfully opened. The serial number of a physical PicoHarp device can be found at the back of the housing. It is a 8 digit number starting with 0100. The leading zero will not be shown in the serial number strings retrieved through PH_OpenDevice or PH_GetSerialNumber.

It is important to note that the list of devices may have gaps. If you have e.g. two PicoHarps you cannot assume to always find device 0 and 1. They may as well appear e.g. at device index 2 and 4 or any other index. Such gaps can be due to other PicoQuant devices (e.g. Sepia II) occupying some of the indices, as well as due to repeated unplugging/replugging of devices. The only thing you can rely on is that a device you hold open remains at the same index until you close or unplug it.

Note that an attempt at opening a device that is currently used by another process will result in the error code ERROR_DEVICE_BUSY being returned from PH_OpenDevice. Unfortunately this cannot be distinguished from a failure to open the device due to insufficient access rights (permissions). Such a case also results in ERROR_DEVICE_BUSY.

As outlined above, if you have more than one PicoHarp 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.

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.

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 PicoHarp 300 uses USB 2.0 bulk transfers. This is supported by the PC hardware that can transfer data to the host memory without much help of the CPU. For the PicoHarp this permits data throughput as high as 5 Mcps and leaves time for the host to perform other useful things, such as on-line data analysis or storing data to disk.

In TTTR mode the data transfer process is exposed to the library user in a single function PH_TTReadData 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 and completing a transfer costs some fixed amount of time, independent of the block size. The maximum transfer block size permitted by PHLib is 131072 (128k event records). However, Libusb has an internal limitation of the block size it can handle in one transfer. This is currently 16 kBytes. Larger transfers are internally broken down into chunks of 16 kBytes. This unfortunately spoils any efforts to improve throughput by means of large block sizes at the PHLib level. Therefore, it may not under all circumsances be sensible to use the maximum size. The demos use a medium size of 32768 records. The throughput limitation of Libusb can be lifted by a patch that permits efficient handling of large blocks. At the time of this writing the patch is not yet officially released. Please email us if you are interested in this solution.

As noted above, the transfer is implemented efficiently without using the CPU excessively. Nevertheless, assuming large block sizes, the transfer takes some time. The operating system 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 best way of doing this is to use multithreading. In this case you design your program with two threads, one for collecting data (i.e. working with PH_TTReadData) 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 it cannot be demonstrated in detail here. Greatest care must be taken not to access PHLib from different threads without strict control of mutual exclusion and maintaining the right sequence of function calls. However, the technique 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 PicoHarp software for Windows, where sustained count rates over 5 millions of counts/sec (to disk) can be achieved on modern PCs.

When working with multiple PicoHarp devices, the overall USB throughput is limited by the host controller or any hub the devices must share. You can increase overall throughput if you connect the individual devices to separate host controllers without using hubs. If you install additional USB controller cards you should prefer PCI-express models. Traditional PCI can become a bottleneck in itself. However, modern mainboards often have multiple USB host controllers, so you may not even need extra controller cards. In order to find out how many USB controllers you have and which bus the individual devices are attached to, you can use lsusb. In case of using multiple devices it is also beneficial for overall throughput if you use multithreading 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.

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 circumsances 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. This ensures that the transfer function returns more promptly. It should be noted that the PicoHarp has a “watchdog” timer that terminates large transfers prematurely so that they do not wait forever. The timeout period is approximately 80 ms. This results in PH_TTReadData 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 it may still be of interest to use a smaller block size. The block size must be an integer muliple of 512.

9. Data Types

The PicoHarp programming library PHLib is written in C and its data types correspond to standard C/C++ data types on 32 bit platforms as follows:

char	8 bit, byte (or character in ASCII)
short int	16 bit, signed integer
unsigned short int	16 bit, unsigned integer
int	32 bit, signed integer
unsigned int	32 bit, unsigned integer
long int	32 bit, signed integer
unsigned long int	32 bit, unsigned integer
float	32 bit, floating point

These types are supported by all major programming languages.

10. Functions exported by PHLib

See **phdefin.h** for predefined constants given in capital letters here. Return values <0 usually denote errors. See **errorcodes.h** for the error codes.

New, starting from v2.0: this is now a multi device library. Device specific functions now take a new device index argument. See section 5.

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

arguments:     errstring = pointer to a buffer for at least 40 characters
               errcode = error code returned from a PH_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 etc.


int PH_GetLibraryVersion(char* vers);

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

return value:  =0      success
               <0      error

Note:   This is the only function you can call before PH_OpenDevice. Use it to ensure
        compatibility of the library with your own application.


//all functions below are device specific and require a device index


int PH_OpenDevice(int devidx, char* serial); //new from v2.0

arguments:     devidx = device index 0..7
               serial = pointer to a buffer for at least 8 characters

return value:  =0      success
               <0      error

Note:   An attempt at opening a device that is currently used by another process will result
        in the return code ERROR_DEVICE_BUSY. Unfortunately this cannot be distinguished from
        a failure to open the device due to insufficient access rights (permissions) which
        also results in  ERROR_DEVICE_BUSY.


int PH_CloseDevice(int devidx); //new from v2.0

arguments:     devidx = device index 0..7

return value:  =0      success
               <0      error

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


int PH_Initialize(int devidx, int mode);

arguments:     devidx = device index 0..7
               mode    0 = histogramming, 2 = T2_Mode 3 = T3_Mode

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

```
//all functions below can only be used after PH_Initialize
```

int PH_GetHardwareVersion(int devidx, char* model, char* vers);

```
arguments:      devidx = device index 0..7
                model = pointer to a buffer for at least 16 characters
                vers  = pointer to a buffer for at least 8 characters

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

int PH_GetSerialNumber(int devidx, char* serial);

```
arguments:      devidx = device index 0..7
                vers = pointer to a buffer for at least 8 characters

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

int PH_GetBaseResolution(int devidx);

```
arguments:      devidx = device index 0..7

return value:   >0      base resolution in ps (corresponds to resoluion in Range 0)
                <0      error
```

int PH_Calibrate(int devidx);

```
arguments:      devidx = device index 0..7

return value:   =0      success
                <0      error

Note:  Calibration is normally only required after warming up and after each PH_Initialize.
```

int PH_SetCFDLevel(int devidx, int channel, int value);

```
arguments:      devidx = device index 0..7
                channel =      number of the input channel (0 or 1)
                value =        CFD discriminator level in millivolts
                                       minimum = DISCRMIN
                                       maximum = DISCRMAX
return value:   =0      success
                <0      error

Note: value is given as a positive number although the electrical signals are actually
negative.
```

int PH_SetCFDZeroCross(int devidx, int channel, int value);

```
arguments:      devidx = device index 0..7
                channel =      number of the input channel (0 or 1)
                value =        CFD zero cross level in millivolts
                                       minimum = ZCMIN
                                       maximum = ZCMAX

return value:   =0      success
                <0      error

Note: value is given as a positive number although the electrical signals are actually
negative.
```

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

arguments:     devidx = device index 0..7
               div =  input rate divider applied at channel 0  (1, 2, 4, or 8)

return value:  =0      success
               <0      error

Note:  The sync divider must be used to keep the effective sync rate at values <= 10 MHz.
       It should only be used with sync sources of stable period. The readings obtained with
       PH_GetCountRate are corrected for the divider setting and deliver the external
       (undivided) rate.


int PH_SetStopOverflow(int devidx, int stop_ovfl, int stopcount);

arguments:     devidx = device index 0..7
               stop_ofl       0 = do not stop, or 1 = do stop on overflow
               stopcount      count level at which should be stopped (max. 65535)

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 65535 in any bin will be clipped.


int PH_SetRange(int devidx, int range);

arguments:     devidx = device index 0..7
               value = Measurement range code
                              minimum = 0            (smallest, i.e. base resolution)
                              maximum = RANGES-1     (largest)

return value:  =0      success
               <0      error

Note:  Range code 0 = base resolution, 1 = 2x base resolution, 2=4x, 3=8x and so on.


int PH_SetOffset(int devidx, int offset);

arguments:     devidx = device index 0..7
               value =        Offset in picoseconds
                                      minimum = OFFSETMIN
                                      maximum = OFFSETMAX

return value:  >=0 new offset
               <0 error

Note:  The true offset is an approximation of the desired offset by the nearest multiple of
       the base resoluion.


int PH_ClearHistMem(int devidx, int block);

arguments:     devidx = device index 0..7
               block = block number to clear

return value:  =0      success
               <0      error


int PH_StartMeas(int devidx, int tacq);

arguments:     devidx = device index 0..7
               tacq = acquisition time in milliseconds
                              minimum = ACQTMIN
                              maximum = ACQTMAX
```

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

int PH_StopMeas(int devidx);

```
arguments:     devidx = device index 0..7

return value:  =0      success
               <0      error

Note:   Can also be used before the CTC expires.
```

int PH_CTCStatus(int devidx);

```
arguments:     devidx = device index 0..7

return value:  0       acquisition time still running
               >0      acquisition time has ended
```

int PH_GetBlock(int devidx, unsigned int *chcount, int block);

```
arguments:     devidx = device index 0..7
               *chcount =     pointer to an array of double words (32bit) of HISTCHAN
                              where the histogram data can be stored
               block = block number to fetch (block>0 meaningful only with routing)

return value:  =0      success
               <0      error

Note:          The current version counts only up to 65535 (16 bits).
               This may change in the future.
```

int PH_GetResolution(int devidx);

```
arguments:     devidx = device index 0..7

return value:  >0      resolution (histogram bin width) in ps, at the current range
               <0      error
```

int PH_GetCountRate(int devidx, int channel);

```
arguments:     devidx = device index 0..7
               channel = number of the input channel (0 or 1)

return value:  >=0     current count rate at this channel
               <0      error

Note:   Allow at least 100 ms after PH_Initialize or PH_SetDyncDivider to get a stable rate
        meter reading. Similarly, wait at least 100 ms to get a new reading. The readings are
        corrected for the sync divider setting and deliver the external (undivided) rate.
```

int PH_GetFlags(int devidx);

```
arguments:     devidx = device index 0..7

return value:  current status flags (a bit pattern)

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

```
int  PH_GetElapsedMeasTime(int devidx);

arguments:     devidx = device index 0..7

return value:  elapsed measurement time in ms
```

SPECIAL FUNCTIONS FOR TTTR MODE (Must have purchased the TTTR mode option)

```
int PH_TTReadData(int devidx, unsigned int* buffer, unsigned int count);

arguments:     devidx = device index 0..7
               *buffer =      pointer to an array of count dwords (32bit)
                              where the TTTR data can be stored
               count          number of TTTR records to be fetched (max TTREADMAX)

return value:  >=0     number of records actually returned in buffer
               <0      error

Note:          Must not be called with count larger than buffer size permits.
               CPU time during wait for completion will be yielded to other
               processes/threads. Function will return after a timeout period of ~80 ms, even
               if not all data could be fetched. Return value indicates how many records were
               fetched. Buffer must not be accessed until the function returns.
```

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

arguments:     devidx = device index 0..7
               meX  = active edge of marker signal X, 0=falling, 1=rising

return value:  =0      success
               <0      error

Note:          PicoHarp devices prior to hardware version 2.0 support only the first three
               markers. For such devices the fourth parameter must still be passed but will
               have no effect.
```

SPECIAL FUNCTIONS FOR ROUTING (Must have PHR 402/403/800)

```
int PH_GetRoutingChannels(int devidx);

arguments:      devidx = device index 0..7

return value:   >0      available number of routing channels
                <0      error


int PH_EnableRouting(int devidx, int enable);

arguments:      devidx = device index 0..7
                enable = 1 -> ebable routing
                enable = 0 -> disable routing

return value:   =0      success
                <0      error

Note:           This function can also be used to detect the presence of a router.


int PH_GetRouterVersion(int devidx, char* model, char* vers);  // new from version 2.0

arguments:      devidx = device index 0..7
                model = pointer to a buffer for at least 8 characters
                vers = pointer to a buffer for at least 8 characters

return value:   >0      available number of routing channels
                <0      error


int PH_SetPHR800Input(int devidx, int channel, int level, int edge);  // new from version 2.0

arguments:      devidx = device index 0..7
                channel = router channel to be programmed (0..3)
                level = trigger voltage level in mV (-1600 .. 2400)
                edge = trigger edge (0=falling, 1=rising)

return value:   >0      available number of routing channels
                <0      error

Note 1: Not all channels may be present
Note 2: Invalid combinations of level and edge may lock up all channels!


int PH_SetPHR800CFD(int devidx, int channel, int dscrlevel, int zerocross); // new from v. 2.0

arguments:      devidx = device index 0..7
                channel = router CFD channel to be programmed (0..3)
                dscrlevel = discriminator level in mV (0 .. 800)
                zerocross = zero crossing level in mV (0 .. 20)

return value:   >0      available number of routing channels
                <0      error

Note 1: CFDs may not be present on all devices
Note 2: Dscrlevel and zerocross are given as positive numbers although the electrical signals
are actually negative.
```

11. Problems, Tips & Tricks

PC Performance Issues

Performance issues with the library under Linux are the same as with the standard PicoHarp software for Windows. The PicoHarp and its software interface are a complex real-time measurement system demanding considerable performance both from the host PC and the operating system. This is why a reasonably modern CPU (1 GHz min.) and at least 512 MB of memory are recommended. The USB 2.0 interface must be configured correctly and use only high speed rated components. If you intend to use TTTR mode with streaming to disk you should also have a fast modern hard disk. However, as long as you do not use TTTR mode, performance issues should not be of severe impact.

Troubleshooting

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

Under Linux the library will access the PicoHarp device through libusb. You need to make sure that libusb has been installed correctly. Normally this is readily provided by all recent Linux distributions. You can use lsusb to check if the device has been detected and is accessible. Please consult the PicoHarp manual for hardware related problem solutions. Note that an attempt at opening a device that is currently used by another process will result in the error code ERROR_DEVICE_BUSY being returned from PH_OpenDevice. Unfortunately this cannot be distinguished from a failure to open the device due to insufficient access rights (permissions). Such a case also results in ERROR_DEVICE_BUSY.

You should also make sure your PicoHarp has the right firmware to use the library. The library option is not free, a license must be purchased. If you do not have it, you can order an upgrade at any time.

To get started, try the readily compiled demos supplied with the library. For first tests take the standard histogramming demos. If this is working, your own programs should work as well. Note that the hard coded setings may not be compatible wih your experimental setup. Then the pre-compiled demo may not work as expected. Only the LabVIEW demo allows to enter the settings interactively.

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 library. In any case your software should issue a warning if it detects versions other than those it was tested with.

New Kernel Versions and Linux Distributions

The library has good chances to remain compatible with upcoming Linux versions. This is because the interface of libusb is likely to remain unchanged, even if it changes internally. You can even revert to an earlier version if necessary. Of course we will also try to catch up with new developments that might break compatibility, so that we will provide upgrades when necessary. However, note that this is work carried out voluntarily and implies no warranties for future support.

Software Updates

We constantly improve and update the sofware 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 register for email notification on software updates. If you wish to receive such notification, please email your name and the serial number of your PicoQuant product(s) to *info@picoquant.com.* You will then receive update information with links for download of any new software release.

Support

The PicoHarp 300 TCSPC system has gone through several iterations of hardware and software improvement as well as extensive testing. Nevertheless, it is a fairly challenging development and some glitches may still occur under the myriads of possible PC configurations, operating systems and application circumstances. We therefore offer you our support in any case of trouble with the system and ask your help to identify any such problems. Do not hesitate to contact PicoQuant in case of difficulties with your PicoHarp or the programming library. However, please note that the Linux library is a free supplement to the Windows version and its development is work carried out voluntarily by single Linux enthusiasts. It therefore implies no warranties for other than voluntary support.

Should you observe errors or unexpected behaviour related to the PicoHarp system, please try to find a precise and reproducible error situation. E-mail a detailed description of the problem and relevant circumstances to *info@picoquant.com.* Please include all PC and operating system details. Your feedback will help us to improve the product and documentation.

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