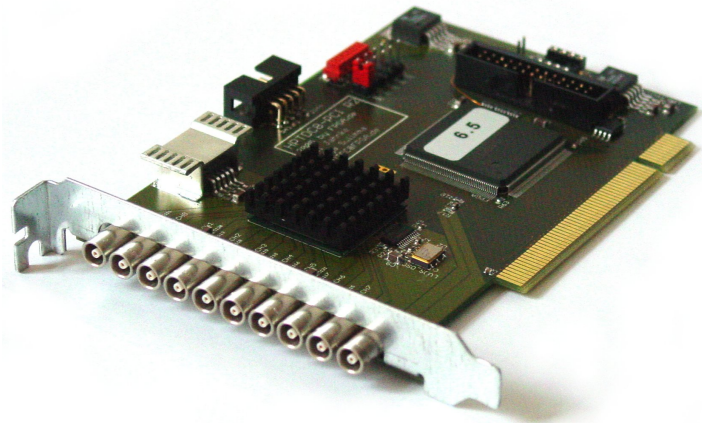


## Features

- 8 NIM compatible inputs on LEMO connectors with 25ps bin size
- 1 NIM compatible input on LEMO connector with 12.8ns bin size
- 12 LVCMOS inputs on SUB-D connector with 12.8ns bin size
- typical deadtime between multiple hits on one channel <5 ns
- unlimited number of hits per trigger
- no dead time due to readout, new data is acquired during readout
- 4M Hits/s readout rate
- 419 $\mu$ s range w. trigger logic enabled
- 2h range without trigger logic, can be extended by software
- adjustable trigger window (size, position of trigger) incl. common start and common stop mode
- easy to use windows driver
- on board storage for calibration data
- support for up to three event-synchronized boards
- 5V, 32-bit, 33MHz PCI target device



## Intended Use

Typical applications for a HPTDC8-PCI include atomic physics experiments (e.g. momentum imaging, time-of-flight spectroscopy), mass spectroscopy and LIDAR.

The HPTDC8-PCI may not be used

- for medical applications except for
  - research
  - imaging systems
  - medical devices used solely as diagnostic tools
- in military devices
- in conjunction with nuclear materials related to defense or power systems
- for space applications with the exception of fundamental research

The HPTDC8-PCI may not be used for military purposes.

If the HPTDC8-PCI is sold, the above restrictions must be incorporated in any resale contract.

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# HPTDC8-PCI

## Time to Digital Converter with 25ps Resolution

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## Concepts

The HPTDC8-PCI continuously records the digital waveforms on its inputs similar to a logic analyzer with an accuracy of up to 25ps.

## Inputs

The board has nine AC coupled inputs on LEMO series 00 coax connectors compatible to the NIM signaling standard. Eight of these are high resolution inputs and one is a low resolution input. Furthermore, it has twelve DC coupled low resolution inputs for 3.3V LVCMOS signals (LVTTTL compatible).

The NIM inputs are terminated with 50 Ohms to ground. A current of -16mA (equivalent to an input voltage of -800mV) is identified as a logic 1, and no current (equivalent to an input voltage of 0V) is identified as a logic 0.

The LVCMOS inputs identify voltages above 2V as logic 1 and voltages below 0.8V as logic 0.

The high resolution inputs have a bin size of 25ps; the low resolution inputs have a bin size of 12.8ns. In order to simplify analysis, high and low resolution inputs use the same data formats. The time for all channels is stored as integer multiples of a unit time, usually 25ps.

Transitions of the input signals are called hits. The data acquisition can be limited to rising or falling signal transitions. Channels can be enabled individually. The high resolution channels are numbered 0 to 7, the optional DC coupled low resolution channels are numbered 9 to 20 and the single AC coupled low resolution channel has channel number 8.

The AC coupling of the front panel inputs is set up for short negative pulses. The width of a pulse must be between 5ns and 3 $\mu$ s to match parameter  $t_{pw}$ .

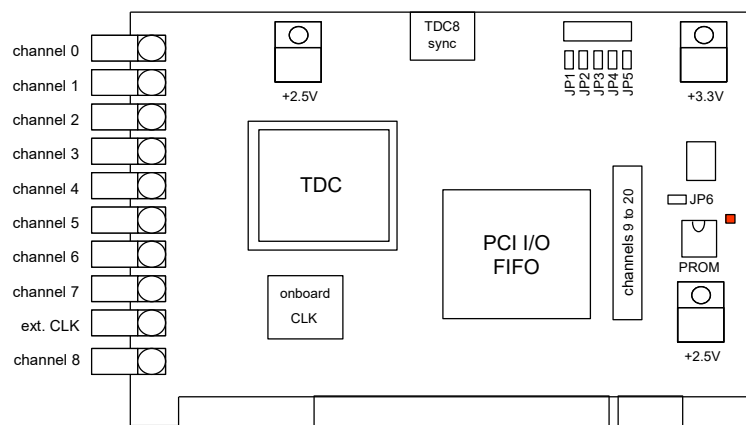


Figure 1: The HPTDC8-PCI card. The high resolution channels 0-7 and the low resolution NIM-channel 8 are located on the left. Low resolution channels 9-20 are connected to the 26-pin ribbon cable connector on the right side. The 10-pin ribbon cable connector at the top is used to connect and synchronize several HPTDC8-PCI.

## Rollover

The data format for a hit contains 24 bits of timing information, which is sufficient for a  $419\mu\text{s}$  time interval at 25ps resolution. The HPTDC8-PCI is collecting data continuously. Whenever the 24 bit counter rolls over a rollover marker is inserted into the data stream with an additional 24 bits for the time measurement (thus allowing measurements of up to  $\sim 2\text{h}$ ). The time interval between two rollovers is called a frame. If there is no hit between two consecutive rollover markers only the last marker appears in the output. However, it is guaranteed that that at least one rollover is output before the 48 bit counter overflows. Using this information measurements with infinite range can be performed if grouping is disabled.

The rollover markers can optionally be suppressed by the driver if grouping is enabled in order to simplify the data format and reduce the data rate for applications that do not need timing information that spans multiple groups. Without grouping enabled rollovers are always output.

## Trigger

An arbitrary input channel can be selected as trigger input. A trigger condition occurs for a signal transition on that input. The time of the trigger condition can be used to group the input data (see below).

Triggers can be rearmed automatically after a programmable delay, after the group associated with the trigger is finished.

## Groups

Hits can be merged to groups (or events in HEP nomenclature). A group will contain hits that occurred within a certain time interval relative to a trigger. Both, the start and end point of the interval can be configured within a range of  $-209.7\mu\text{s}$  to  $209.7\mu\text{s}$ . Figure 2 shows a typical data acquisition scenario in triggered mode. The size of the acquisition window is set by the configuration parameters **GroupRangeStart** and **GroupRangeEnd**. The falling edge of the trigger signal is used (**TriggerEdge falling**).

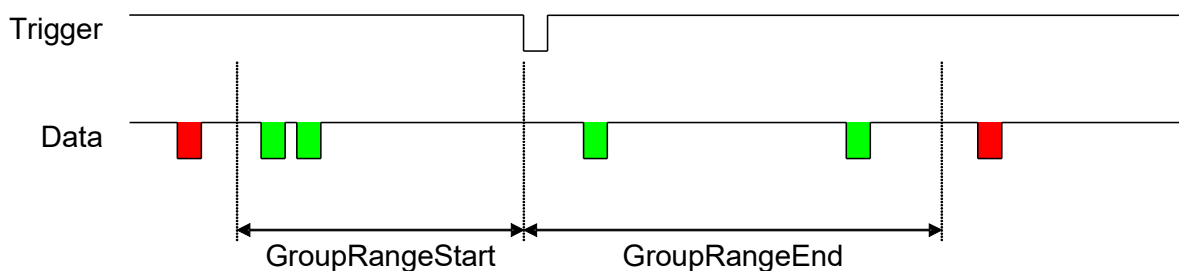


Figure 2: Data acquisition in triggered mode. Hits within the group's range (green) are acquired, hits outside that range (red) are rejected.

Data within a group has timing values relative to the trigger event's time. Hits can be assigned to multiple groups. If a new trigger event occurs inside the range of a group one of three behaviors

can be selected:

- 1 No trigger is issued and the trigger event is recorded as a hit on the trigger channel if data taking for this channel is enabled.
- 2 A new trigger is issued, the previous group is ended and data in the overlapping range is assigned to the new group.
- 3 A new trigger is issued and data in the overlapping range are assigned to both groups possibly including the trigger event.

The range of a group is limited to 419.4 $\mu$ s.

Figure 3 displays the three types of behavior. On top, a trigger is suppressed using the configuration parameter **TriggerDeadTime**. In the middle of Figure 3, a group is ended by a consecutive trigger. A new group is started. Both groups' ranges are truncated. This behavior is enabled using the configuration parameter **AllowOverlap false**. Figure 3 (bottom) shows the case of overlapping groups (**AllowOverlap true**). Hits inside the overlapping region of both groups are assigned to each group, the timing value is calculated with respect to the corresponding trigger time.

If grouping is disabled, the timing value for a hit is an unsigned integer relative to the last rollover marker.

A group in the data stream ends with the beginning of a new group or with a rollover marker.

If grouping and rollovers are enabled there is a rollover marker immediately preceding each group marker, even if two consecutive groups start in the same frame.

As described before, a trigger deadtime can be set in order to suppress consecutive triggers in the chosen timing interval. This can be used to avoid overlapping groups or create an intentional dead time to remove unwanted data from the data stream.

## Signal Level Information

If grouping of data is enabled, input transitions, that occur outside a group are not recorded. If the signal has no transition within the group, the level of the signal is unknown. Therefore the signal levels can be output at the beginning of each group. This feature can be enabled individually for each board.

If multiple TDCs are used the level information is not guaranteed to appear directly at the beginning of a group for all TDCs. Level information for each board is guaranteed to appear before the first signal transition of that board.

Any errors that might cause hits to be lost can cause incorrect level information. Once there is a another hit received on a channel the level information will be correct again.

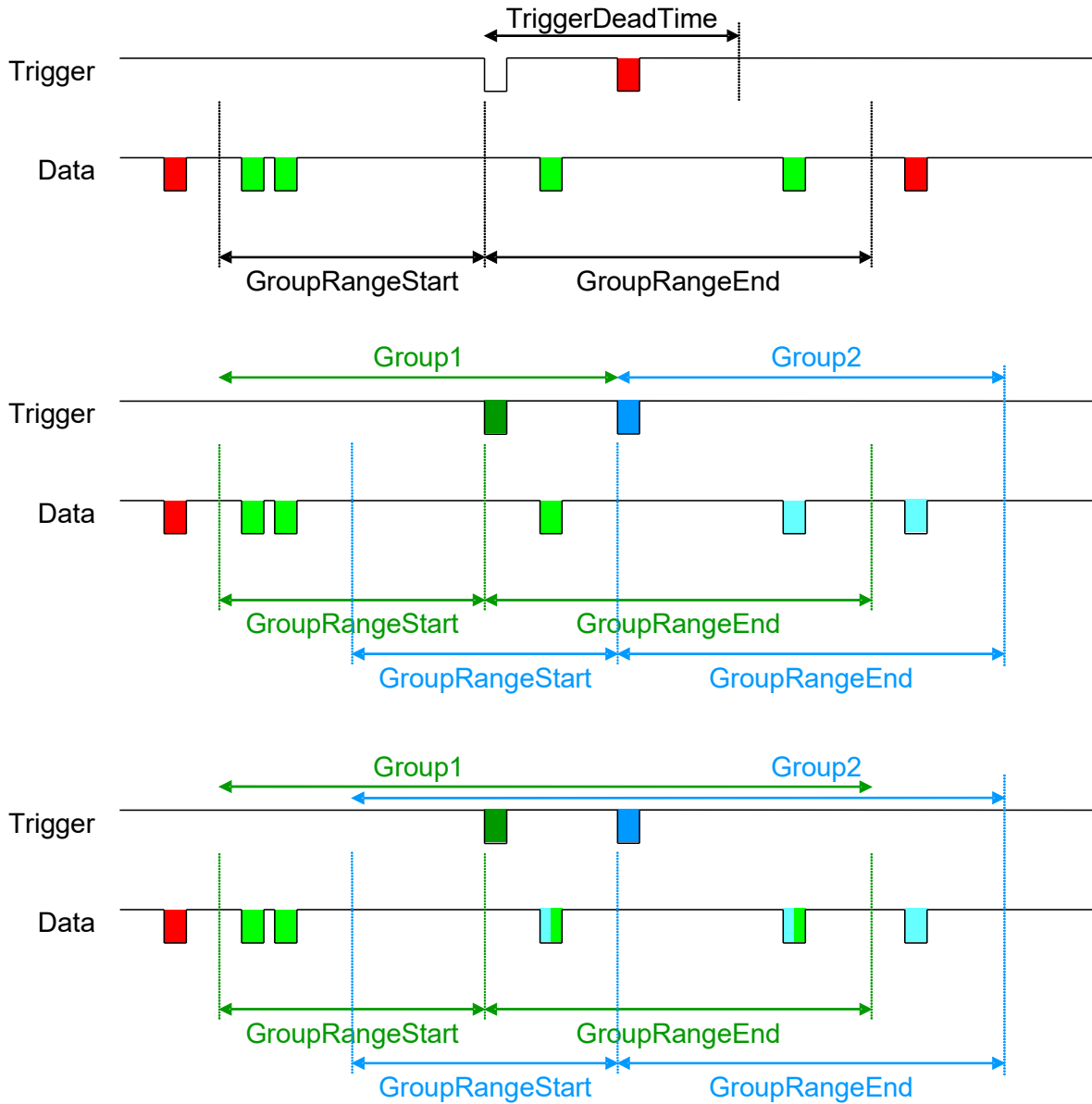


Figure 3: The three different types of grouping described in the text.

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# HPTDC8-PCI Time to Digital Converter with 25ps Resolution

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## Data Format

The readout data is a stream of 32 bit words in little endian byte order. Each word represents a signal transition on an input or a special marker.

### Falling transition

|       |         |                 |
|-------|---------|-----------------|
| 31-30 | 29 - 24 | 23 - 0          |
| 10    | channel | transition time |

The transition time is a 24 bit signed integer when inside a group or an unsigned integer otherwise.

### Rising transition

|       |         |                 |
|-------|---------|-----------------|
| 31-30 | 29 - 24 | 23 - 0          |
| 11    | channel | transition time |

The transition time is a 24 bit signed integer when inside a group or an unsigned integer otherwise.

### Error with channel information

|       |         |         |        |
|-------|---------|---------|--------|
| 31-30 | 29 - 24 | 23 - 16 | 15 - 0 |
| 01    | channel | error   | count  |

Error numbers below 128 are lost hits.

If the bit with weight 64 is set and multiple boards are present, applications should reset the data acquisition if the trigger channel is in the group the error occurred in.

Any errors that might cause hits to be lost can cause incorrect level information. Once there is a another hit received on a channel the level information will be correct again.

| Error Number | Source | Description  |
|--------------|--------|--|
| 0            | FPGA   | hires data lost due to fpga fifo overflow                |
| 16           | SOFT   | data lost due to software buffer overflow                |
| 32           | FPGA   | lores data lost due to fpga fifo overflow                |
| 96           | FPGA   | triggers lost due to fpga fifo overflow                  |
| 112          | SOFT   | trigger lost due to software buffer overflow             |
| 160          | TDC    | TDC chip error, possibly hit lost                        |
| 128          | FPGA   | unknown error, should occur only for prototype           |
| 129          | FPGA   | FPGA fifo empty  |
| 255          | SOFT   | boards might be out of sync, user should reset the board |

### Group

|         |         |              |
|---------|---------|--------------|
| 31 - 28 | 27 - 24 | 23 - 0       |
| 0000    | Id      | trigger time |

The time values of the following hits should be added to the trigger time to obtain the absolute time of the transition. The id currently is always 0 but could be used to identify multiple trigger conditions in future versions.

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## HPTDC8-PCI Time to Digital Converter with 25ps Resolution

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### Rollover

|          |                             |
|----------|-----------------------------|
| 31 - 24  | 23 - 0                      |
| 00010000 | upper 24 bits of time stamp |

The time between two rollovers is called a frame.

### Level information

|         |         |        |
|---------|---------|--------|
| 31 - 27 | 26 - 21 | 20 - 0 |
| 00011   | n       | Level  |

At the beginning of a group the levels of the input signals can optionally be output. One word contains the levels of 21 inputs beginning at channel n.

### Resolution

|          |                        |
|----------|------------------------|
| 31 - 24  | 23 - 0                 |
| 00100000 | bin size in fs (25000) |

This word should be added once at the beginning of each output file to describe the size of a timing bin. Currently there exist two types of TDCs: Most have 25.00000ps resolution and starting with serial number 9.50 some TDCs have 25.117348ps resolution.

## Configuration File

TDC, FPGA and the driver software are configured by text based configuration files that can also contain calibration data.

Any number of configuration files can be read in with the newer configuration overriding the older ones. This allows to have configuration files that each describe individual boards, experiment set-ups and readout situations and combine them as desired.

Configuration files consist of independent lines that can appear in any order. Each line configures zero or one parameter. If the same parameter appears multiple times in a set of configuration files the last occurrence is used.

Lines starting with a sharp “#” are comments and are ignored by the driver.

Anything behind a double slash “//” to the end of a line is treated as a comment.

There may be any number of empty lines.

All other lines consist of a parameter name and a value. Both, values and parameter names, are case insensitive.

## Values

Values can have different types as follows. If no value is specified a default value is loaded from the on board PROM.

### Boolean

A value that is either true or false. The values “1”, “t”, “true”, “on”, “enable” and “enabled” are recognized as true. The values “0”, “f”, “false”, “off”, “disable” and “disabled” are recognized as false.

### Integer

Any integer in decimal base such as “5”, “023” or “-1”.

### Time

A floating point number in C-notation such as “5”, “5.2”, “1.7e-3” followed by a time unit. Allowed units are “s”, “ms”, “us”, “μs”, “ns”, “ps” and “fs”.

### Channel mask

A value of this type defines a set of channels that the parameter applies to. The format is a list of ranges or individual channels separated by commas. A range consists of a lower and upper channel separated by a minus. The lower and upper bound are included in the range. Examples are „1” or „7, 9, 14” or „1-4,15”. To include all channels use „0-20”. To disable all channels use „no” or „none”

### Edge

An input transition. The value “falling” denotes a transition from a higher electrical potential to a lower potential. “rising” denotes the opposite transition.



## Parameters

Parameters are named with a case insensitive string of alphabetic characters.

Array parameters are followed by ":" and an index.

If multiple TDCs are present most parameter names can be followed by "@" and a number indicating for which TDC the parameter shall be set. Otherwise the parameter is set for all TDCs. Numbering of TDC boards starts with 0.

Additionally, for parameters that can be set channel wise, the name can be followed by "#" and a number to indicate for which channel the parameter shall apply. Otherwise the parameter is applied for all channels.

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## General Parameters configurable by the User

| name           | type | scope   | min   | max  | default | description   |
|----------------|------|---------|-------|------|---------|---|
| RisingEnable   | mask | channel |       |      | none    | Record 0 to 1 transitions for these channels  |
| FallingEnable  | mask | channel |       |      | 0-63    | Record 1 to 0 transitions for these channels  |
| TriggerEdge    | edge | global  |       |      | falling | Trigger on falling or rising edge   |
| TriggerChannel | int  | board   | 0     | 63   | 0       | Which channel to use as a trigger   |
| OutputLevel    | bool | board   | false | true | false   | Keep track of signal levels   |
| ExternalClock  | bool | global  | false | true | false   | Use external clock source   |
| VHR            | bool | global  | false | true | true    | Enables the TDC's very high resolution mode with a bin size of 25ps. If disable the bin size is set to 100ps increasing the TDC's data throughput by a factor of 4, thus increasing lossfree hit rates (see page 31). |
| UseINL         | bool | global  | false | true | true    | Use INL correction.   |
| UseFineINL     | bool | global  | false | true | false   | Use better INL correction with ReadTDCHit(). Disables coarse INL correction. Should not be set when using Read().   |
| BufferSize     | int  | global  | 16    | 27   | 23      | Number of bits in the number of hits in the buffer. 23 Bits provides a buffer of 8MHits   |
| Prescaler      | int  | channel | 1     | 32   | 1       | For channels 9 to 14: report only one out of N edges.   |

## HPTDC8-PCI Time to Digital Converter with 25ps Resolution

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### Grouping Parameters configurable by the User

| name             | type | scope  | min      | max     | default | description   |
|------------------|------|--------|----------|---------|---------|---|
| OutputLevel      | bool | board  | false    | true    | false   | Keep track of signal levels   |
| GroupingEnable   | bool | global | false    | true    | true    | Enable grouping   |
| AllowOverlap     | bool | global | false    | true    | false   | If a hit falls within multiple groups copy it to all groups or just to the last one   |
| TriggerDead-Time | time | global | 0        | 1s      | 100ms   | Time during which no new triggers are accepted after a trigger  |
| GroupRangeStart  | time | global | -209.7μs | 209.7μs | 0       | Smallest time value relative to group marker to be included in group. (Set negative for common stop)  |
| GroupRangeEnd    | time | global | -209.7μs | 209.7μs | 209.7μs | First time value relative to group marker not to be included in group, (Set positive for common start)  |
| OutputRollovers  | bool | global | false    | true    | true    | Include rollover markers in the data format. Rollovers can only be disabled if grouping is enabled.   |
| GroupTimeout     | time | global | 0        | 1h      | 200ms   | When using multiple boards the driver assumes that after this time interval all data from an event has arrived in system memory. Ignored for single board setups. |
| OutputLevel      | bool | board  | false    | true    | false   | Keep track of signal levels   |

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## Other Parameters

These parameters should usually be kept at their default values. They may be used for debugging or testing or in special usage cases.

| name                                    | type | scope        | min   | max    | default                      | description   |
|---|------|--------------|-------|--------|------------------------------|---|
| DllTapAdjust:0<br>to<br>DllTapAdjust:31 | int  | board        | 0     | 7      | From<br>PROM                 | Lookup table for DNL correction   |
| DelayTap:0<br>to<br>DelayTap:3          | int  | board        | 0     | 7      | From<br>PROM<br>(7, 7, 0, 0) | Calibrate very high resolution clock  |
| INL:0<br>to<br>INL:1023                 | int  | chan-<br>nel | 0     | 1023   | From<br>PROM                 | Lookup table for INL correction   |
| UseClock80                              | bool | global       | false | true   | true                         |   |
| MMXEnable                               | bool | global       | false | true   | true                         | Use 64 bit reads in non-dma mode  |
| DMAEnable                               | bool | global       | false | true   | true                         | Copy data using direct memory access. Should remain true for drivers 3.0.1 and newer. |
| SSEEnable                               | bool | global       | false | true   | false                        | Use 128 bit reads in non-dma mode   |
| ClockDelayPattern                       | int  | board        | 0     | 0xffff | 0x0800                       | don't change  |

## Deprecated or Obsolete Parameters

These parameters have been valid in old versions of the driver but should not be used anymore.

| name                   | type | scope  | min   | max  | default | description  |
|------------------------|------|--------|-------|------|---------|--|
| SoftwareSync           | bool | global | false | true | false   | Enable if more than one card is used, but no external clock source is present. |
| TDC8Sync               | bool | global | false | true | false   | Synchronize a TDC8 and a HPTDC8-PCI board.                                     |
| SyncValidation-Channel | int  | global | 0     | 21   | 8       |  |
| SimulateExternalClock  | bool | global | false | true | false   |  |

## Multiple boards

Unique channel numbers are assigned to each board. The second board will usually start with channel number 21, and the third one with channel number 42. A serial number of the type X.Y is printed on every TDC card (see Figure 4). X denotes the year of production minus 2000, Y is an integer greater than zero. The card with the lowest number is initialized as the first board, the one with the next higher number as the second, and the board with the highest number is the third board. For example: three cards with the numbers 6.7, 7.11 and 6.12 are installed. The first card (with channel numbers 0 to 20) is the one with number 6.7, the second card (channels 21 to 41) is the one with serial number 6.12 and the third card (channels 42 to 62) is card 7.11.

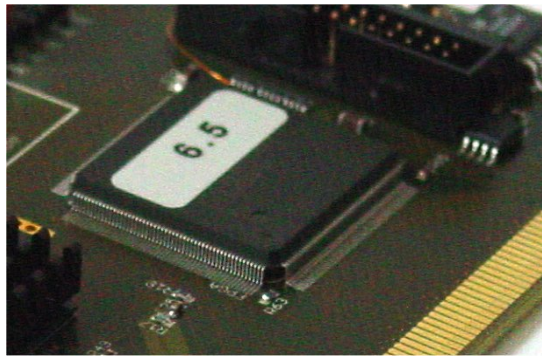


Figure 4: The card's serial number located on the PCI-interface chip. The first digit denotes the year of production, the second is a serial number that is unique within that year.

## Multiple boards with external clock reference

This is the preferred mode of operation when using multiple boards: a common clock signal is connected to the clock input of each board. This signal must have a frequency of 78.125MHz.

In this case all acquisition modes described above are supported and the additional measurement error described above is avoided.

Using an external clock, a trigger signal needs to be connected to one TDC board only. This must be the **first** board (channels 0 to 20).

In order to enable the external clock source the configuration parameter **ExternalClock** needs to be set to **true**.

The resolution is reported as 25.00000 ps when external clocking is selected, relying on the external clock having the correct frequency.

## Calibration

There are multiple levels of calibration: firstly, for the very high resolution mode of the HPTDC8-PCI the bin size for the lower two bits of measurement can be adjusted using delay taps inside the TDC. Secondly, the INL of the data can be corrected using a table lookup in the driver software. It is an option to use a different bin size after table lookup than before table lookup.

For the table lookup the last ten bits of each timing value are used to index a table that contains 1024 entries for each channel with the last bits of the corrected measurement.

The boards are delivered with calibration data stored in an onboard flash PROM. The driver uses this data by default. Users can easily create their own calibration data and feed it to the driver or even program new data to the onboard prom.

When using the Read() method data is return with 25ps quantization with both corrections applied.

When using the ReadTDCHits() method data is returned with 1ps quantization. The average bin size will still be 25ps, but the information about the individual bin sizes can be preserved. To use this feature set the "useFineINL" property to "true".

The reference frequency is determined by a temperature compensated crystal oscillator with the specifications listed on page 30. The absolute frequency error is dominated by the initial accuracy and aging of the oscillator. Applications that have stringent requirements for the absolute size of longer intervals might want to compensate for this error. The frequency can be determined by connecting a pulse per second (PPS) signal from a frequency normal such as a GPS receiver to one of the inputs and measure the average distance of the pulses.

## Programming Interface

The driver API defines the following methods. Both the C++ and the C# syntax is shown. The C# version can be used in any language that supports the .net platform such as VisualBasic, J# or managed C++.

### Exceptions

Many methods in the API throw exceptions when an error occurs. They all have the type `TDCConfigException` which is defined as:

```
class TDCConfigException {  
public:  
    const char * errorString;  
};
```

The error string contains additional information about the nature of the exception.

The application developer can choose to catch the exception and continue with program execution. Optionally the error string could be logged or presented to the user.

If the exception is not caught the application will be terminated.

### Startup and cleanup

#### **void Init()**

#### **void Init()**

Should be called once before using the `TDCManager`. **Init()** detects all present TDC devices, acquires all available information on the those devices and maps the address space for PCI access. It also reads the „global.cfg“ configuration file if present in the current directory.

Can throw all exceptions that are related to parsing the configuration file.

#### **void CleanUp()**

#### **void Cleanup()**

Should be called once before exiting the program.

#### **int GetTDCCount()**

#### **int GetTDCCount()**

Returns the number of HPTDC boards found in the system. From 0 to 3.

### Configuration

The TDC and readout configuration is manipulated via a set of methods. The parameters do not take effect before the **Reconfigure()** method is called.

If a parameter is set multiple times the last value is used.

**bool SetParameter(const char \* config)**  
**bool SetParameter(string config managed)**  
**bool ReadConfigString(const char \* parameter)**  
**bool ReadConfigString(string configManaged)**

Read in a string with the syntax of a configuration file line as described in the previous section. The string might contain multiple lines.

Can only be called if the TDC is stopped (states 0, 1 and 2). Throws an exception otherwise.

Returns false if there were illegal parameters or syntax errors. True otherwise.

**bool SetParameter(const char \* property, const char \* value)**  
**bool SetParameter(string propManaged, string valueManaged)**

Set the value of a parameter identified by the parameter name.

Can only be called if the TDC is stopped (states 0, 1 and 2). Throws an exception otherwise.

Returns true if successful, false if there was an error.

**bool ReadConfigFile(const char \* filename)**  
**bool ReadConfigFile(string filenameManaged)**

Read in a configuration file.

Can only be called if the TDC is stopped (states 0, 1 and 2). Throws an exception otherwise.

Can also throw exceptions generated while opening or reading the file.

Returns true if successful, false if there was an error.

**void Reconfigure()**  
**void Reconfigure()**

Writes configuration data to the device. Use after configuration has been changed. This operation is slow.

Can only be called if the TDC is stopped (states 0, 1 and 2). Throws an exception otherwise.

Throws an exception if a parameters cannot be parsed.

## Reflection

**const char \* GetParameter(const char \* parameter)**  
**String GetParameter(string parameterManaged)**

Get the value of a parameter. If the parameter does not exist or has not been set an empty string is returned.

**const char \*\* GetParameterNames(int & count)**  
**string[] GetParameterNames()**

Get the names of all parameters that are set. The c++ Version returns the number of elements in the array in the count variable.

**int GetDriverVersion()**  
**int GetDriverVersion()**

The lowest three bytes returned are the three digits of the driver Version.



## Control

### **void Start()**

### **void Start()**

Configure all TDCs with the parameters set by the methods described in the previous section and start all TDCs. This method can require several milliseconds to complete when called from state "NOT\_CONFIGURED". To precisely time the start of the data acquisition call **reconfigure()** first.

If called from state NOT\_CONFIGURED exceptions thrown from reconfigure() can occur. Also throws an exception if called from state UNINITIALIZED.

### **void Stop()**

### **void Stop()**

Stop taking data and turn off TDCs. The state of the hardware and software queues is undefined after this operation. No additional data should be read out. To get all data in the queues call **Pause()** and empty the buffers before calling this method.

The TDC is put into a low power state that can only be recovered by a **Start()** operation.

Throws an exception if called in states UNINITIALIZED or SHUTDOWN.

### **void Pause()**

### **void Pause()**

Stop taking data. Data already in the hardware and software buffers is left intact and can be read out. The TDC hardware is kept in a state that allows to resume data acquisition immediately. Frame counters continue to count.

Throws an exception when called from a state other than PAUSED or RUNNING.

### **void Continue()**

### **void Continue()**

Quickly continue taking data after a **Pause()**. Buffers are left intact and frame counters are left unaltered.

It is legal to use **Start()** to resume operation instead.

Throws an exception when called from a state other than PAUSED or RUNNING.

### **void ClearBuffer()**

### **void ClearBuffer()**

Clears all buffers. Only meaningful in state PAUSED.

Throws an exception if called in state RUNNING. Has no effect in other states.

**TDCInfo GetTDCInfo(int index)**  
**HPTDCInfo GetTDCInfo(int index)**

Get the information on TDC card number *index*.  
Throws an exception if called in state UNINITIALIZED.  
Returns an object that contains the following data:

```
class TDCInfo  
class HPTDCInfo  
int index;  
int channelStart;  
int channelCount;  
int highResChannelCount;  
int highResChannelStart;  
int lowResChannelCount;  
int lowResChannelStart;  
double resolution;  
DWORD serialNumber;  
int version;  
int fifoSize;  
int *INLCorrection; //in .net : int[] INLCorrection;  
unsigned short *DNLData; //in .net: short[] DNLData;  
bool flashValid;  
int bufferSize;  
unsigned char boardConfiguration;
```

**index**

The index of this board, e.g. 0 for the first board.

**channelStart**

The number of the card's first channel as initialized by the driver. For example: if two HPTDC8-PCI card's are present, the second card's channel numbers are usually 21 to 41. That card's first channel is therefore channel number 21.

**channelCount**

Total number of channels.

**HighResChannelCount**

Number of channels with high resolution.

**highResChannelStart**

Number of first channel with high resolution.

**lowResChannelCount**

Number of channels with low resolution.

**lowResChannelStart**

Number of first channel with low resolution.

**resolution**

The TDC card's bin size of the high resolution channels.

This value can be different for external and internal clocking. The structure should be updated when changing this parameter.

**serialNumber**

The card's unique serial number. The highest byte denotes the year of production minus 2000, the 3 lower bytes a serial number.

**version**

The lowest byte describes the board revision, the next higher byte the firmware revision.

**fifoSize**

The size of the on board PCI-FIFO in data words.

**\*INLCorrection**

Pointer to an array containing the current INL correction table. The array has a size of 8 x 1024 entries, starting with channel 0, value 0, followed by channel 0, value 1 etc.

**\*DNLData**

Pointer to an array containing the bin sizes before INL correction. These are relative sizes that must be normalized to the sum of values for each channel.

**flashvalid**

Set to true if valid calibration flash content has been detected.

**bufferSize**

Size of the of the software buffer in hits.

**boardConfiguration**

Differentiates various options in the board assembly.

**int GetState()**

**int GetState()**

Returns the current state of the TDCManager.

```
const static int STATE_UNINITIALIZED = 0;  
const static int STATE_NOT_CONFIGURED = 1;  
const static int STATE_CONFIGURED = 2;  
const static int STATE_RUNNING = 3;  
const static int STATE_PAUSED = 4;  
const static int STATE_SHUTDOWN = 5;
```

**long long GetTDCStatusRegister()**

**long GetTDCStatusRegister()**

Returns a 64 bit number that can be sent to the manufacturer for debugging purposes.

## Readout

### **int Read(HIT \*out, int size)**

### **int Read(int[] buffer)**

Copy TDC data into buffer of size *count*. If grouping is enabled one group is read. Otherwise all available data up to the size of the buffer is read. The number of data words that were read is returned as an integer.

If grouping is enabled and no group is found within a certain time interval Read() returns 0.

The data returned has the format described earlier in this document. To get the absolute time multiply the integer values reported by resolution as specified in the TDCInfo structure.

### **int ReadTDCHit(TDCHit \*buffer, int length)**

### **int ReadHPTDCHit(HPTDCHit buffer)**

Copy TDC data into buffer of size *count*. The number of data words that were read is returned as an integer. All available data up to the size of the buffer is read.

Uses a data format that is easier to use and provides a better DNL and INL than Read().

Uses more memory and CPU cycles.

Does not support grouping.

Output data is sorted by timestamp.

The data returned uses a structure that obsoletes rollovers. Also, times are reported in multiples of one picosecond, independently of the TDCs native resolution. A more fine-grained INL correction is used in this mode slightly reduce the measurement error of the TDC.

“bin” is auxiliary information that can be ignored in normal operation.

```
struct TDCHit {
    public:
    const static int FALLING = 0;
    const static int RISING = 1;
    const static int TDC_ERROR = 2;

    long long time;
    unsigned char channel;
    unsigned char type;
    unsigned short bin;
};
```

If type is set to 2 an error word in the format described on page 6 will be copied into the lower 32 bits of time.

## TDC Driver State Machine

A sketch of the user view of the driver's architecture is shown in Fig. XXX. After starting the PC the driver will wait in the state Idle until the user invokes an Init command. The Init command loads the parameters given in the standard configuration file („global.cfg”) to the driver's registers. At this point, depicted in Fig. XXX by the state Not configured, the TDC-card itself is not yet config-

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## HPTDC8-PCI Time to Digital Converter with 25ps Resolution

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Rev 3.9.3 as of 2019-10-21  
Firmware 7, Driver v3.9.3

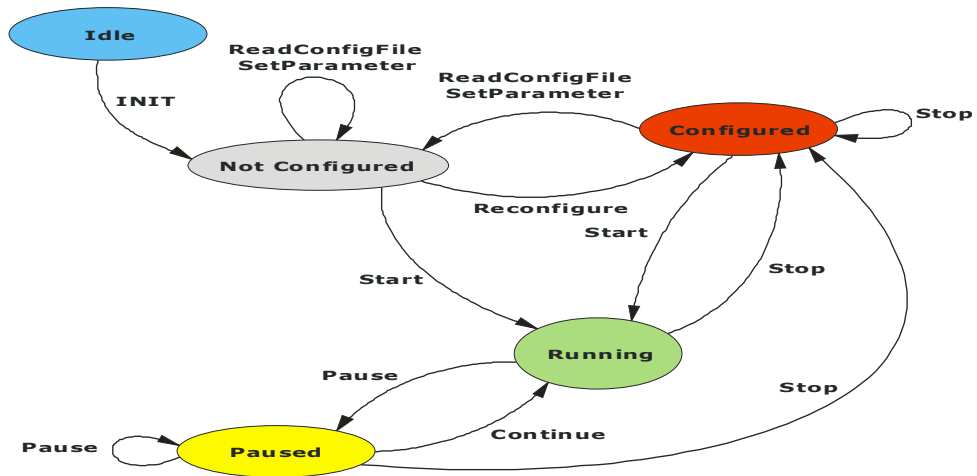
User Manual

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ured. The user can now change any parameter by using the functions `ReadConfigFile` or `SetParameter`. The user may now invoke a `Start` command in order to start acquiring data. In this case the driver will automatically configure the TDC the card using the parameters set by the user and run the data acquisition. As configuring the TDC card takes up to 1 second, a second way of starting the data acquisition is implemented, as well: by using the `Reconfigure` the TDC card is configured and then ready for data acquisition (state `Configured` in Fig. XXX). A `Start` command will now start data acquisition instantaneously. This path is intended for users who need a low latency between an intended start and the real start of the data acquisition.

The command ***Pause*** will stop the data acquisition but leave the TDC card fully configured. Being in the ***Pause***-state a ***Continue*** will immediately restart the data acquisition. If the user intends to change some of the TDC's parameters or to clear the buffers a ***Stop*** command is necessary taking the driver back to the state ***Configured***. If the parameters remain unchanged, a ***Start*** will immediately restart the data acquisition. By changing parameters the driver returns to the ***Not Configured*** state, a restart from that state will take longer as the TDC card needs to be reconfigured before the data acquisition is invoked.

The current state can be queried with the ***getState()*** method.



Page A0

Figure 5: The driver's state machine as seen by the user.

## C++ Code Example

### 25ps mode

```
#include "tdcmanager.h"
#include <string>
#include <list>
#include <fstream>

int main(int argc, char* argv[])
{
    TDCManager manager(0x1A13, 0x0001);
    try {
        manager.Init();
        manager.ReadConfigFile("myexperiment.cfg");
        manager.Start();
    } catch (TDCCConfigException& e) {
        return -1;
    }

    int amountToRead = 1000000;
    HIT buffer[2000];
    ofstream of("test.dat", ios::out | ios::binary);

    while(amountToRead > 0)
    {
        int count = manager.Read(buffer,2000);
        for(int i = 0; i < count && i < amountToRead; i++) {
            of.write((const char*)(buffer +i), sizeof(HIT));
        }
        amountToRead -= count;
    }
    manager.Stop();
    manager.CleanUp();
    return 0;
}
```

## C# Code Example

### 1ps mode

```
using cronologic;
using System.IO;
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace application {
    class Program {
        static void Main(string[] args)
        {
            HPTDCManager manager = new HPTDCManager();

            try {
                manager.Init();
                manager.ReadConfigFile("myexperiment.cfg");
                manager.Start();
            } catch (HPTDCException e) {
                System.Console.WriteLine(e.Message);
                return;
            }

            int amountToRead = 1000000;
            HPTDCHit[] buffer = new HPTDCHit[2000];

            StreamWriter newFile = new StreamWriter("myexperiment.csv");

            while(amountToRead > 0)
            {
                int count = manager.ReadHPTDCHit(buffer);
                for(int i = 0; i < count && i < amountToRead; i++) {
                    newFile.Write(buffer[i].channel + ", ");
                    newFile.Write(buffer[i].type + ", ");
                    newFile.WriteLine(buffer[i].time);
                }
                amountToRead -= count;
            }
            newFile.Close();
            manager.Stop();
            manager.CleanUp();
        }
    }
}
```



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HPTDC8-PCI  
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with 25ps Resolution

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}  
}

## Lowres Connector Pinout

| Signal | Pin Number |    | Signal        |
|--------|------------|----|---------------|
| 3.3V   | 1          | 2  | reserved      |
| GND    | 3          | 4  | reserved      |
| GND    | 5          | 6  | CH11          |
| GND    | 7          | 8  | CH12          |
| GND    | 9          | 10 | CH13          |
| GND    | 11         | 12 | CH14          |
| 2.5V   | 13         | 14 | CH15          |
| GND    | 15         | 16 | CH16          |
| GND    | 17         | 18 | CH17          |
| GND    | 19         | 20 | CH18          |
| GND    | 21         | 22 | CH19          |
| GND    | 23         | 24 | CH20          |
| 5V     | 25         | 26 | not connected |

### **HPTDC-MDS and HPTDC-MDS-RoHS**

#### **lowres connector pinout**

## Electrical Characteristics

### Environmental Conditions

The inboard is designed to be operated under the following conditions.

| Symbol | Parameter                 | Min | Typ | Max | Units |
|--------|---------------------------|-----|-----|-----|-------|
| T      | Ambient Temperature       | 5   |     | 50  | °C    |
| RH     | relative humidity at 31°C | 30  |     | 70  | %     |

### Power Supply

| Symbol | Parameter                     | Min           | Typ | Max  | Units |
|--------|-------------------------------|---------------|-----|------|-------|
| I      | PCI 5V rail power consumption |               |     | 2.5  | A     |
| VCC    | PCI 5V rail power supply      | 4.75          | 5   | 5.25 | V     |
|        | other PCI power supply rails  | not connected |     |      |       |

### Hi-Res Inputs

AC coupled NIM compatible inputs with parallel termination.

The idle level is high, signals are given by negative pulses.

| Symbol          | Parameter                                     | Min   | Typ   | Max   | Units    |
|-----------------|---|-------|-------|-------|----------|
| $V_{DC}$        | DC input voltage                              | -10   |       | 10    | V        |
| $\Delta V_{IL}$ | AC Pulse low level (relative to DC level)     | -1.5  |       | -0.5  | V        |
| $\Delta V_{TH}$ | AC switching threshold (relative to DC level) | -0.34 | -0.24 | -0.14 | V        |
| $V_T$           | termination voltage                           |       | 0     |       | V        |
| Z               | input impedance                               |       | 50    |       | $\Omega$ |
| $t_{pw}$        | pulse width                                   | 5     |       | 3000  | ns       |
| $t_{dead}$      | dead time after edge                          |       | 5     | 10    | ns       |

## Trigger Input

AC coupled NIM compatible input with parallel termination.

The idle level is high, signals are given by negative pulses.

|                    |   |      |       |      |          |
|--------------------|---|------|-------|------|----------|
| VTDC               | DC input voltage                              | -10  |       | 10   | V        |
| $\Delta$ VTIL      | AC pulse low level (relative to DC level)     | -1.5 |       | -0.5 | V        |
| $\Delta$ VTTH      | AC Switching threshold (relative to DC level) |      | -0.38 |      | V        |
| ZT                 | input impedance                               |      | 50    |      | $\Omega$ |
| VTT                | termination voltage                           |      | 0     |      | V        |
| tTp <sub>w</sub>   | pulse width                                   | 30   |       | 3000 | ns       |
| tT <sub>dead</sub> | pulse separation                              | 30   |       |      |          |

## Clock Input

AC coupled input with 50 $\Omega$  thievenin termination after the capacitor.

| Symbol          | Parameter                    | Min  | Typ               | Max  | Units    |
|-----------------|------------------------------|------|-------------------|------|----------|
| V <sub>CH</sub> | input common mode voltage    | -4   |                   | 7    | V        |
| V <sub>CL</sub> | input amplitude peak-to-peak | 0.8  |                   | 3.3  | V        |
| Z <sub>c</sub>  | input impedance              |      | 50                |      | $\Omega$ |
| t <sub>c</sub>  | clock period                 | 12.5 | 12.8 <sup>1</sup> | 13.1 | ns       |
|                 | duty cycle                   | 45   | 50                | 55   | %        |

1 Deviation from the nominal period will scale measurement results.

## Lowres Inputs

DC coupled CMOS compatible inputs with parallel termination.

| Symbol    | Parameter           | Min | Typ  | Max | Units    |
|-----------|---------------------|-----|------|-----|----------|
| $V_{LIH}$ | input high level    | 2   |      | 3.3 | V        |
| $V_{LIL}$ | input low level     | 0   |      | 0.8 | V        |
| $V_{LTH}$ | switching threshold |     | 1.65 |     | V        |
| $V_{LT}$  | termination voltage |     | 0    |     | V        |
| $V_L$     | input impedance     |     | 100  |     | $\Omega$ |

## TDC8 Sync Input

DC coupled CMOS compatible inputs with parallel termination.

| Symbol    | Parameter           | Min | Typ  | Max | Units    |
|-----------|---------------------|-----|------|-----|----------|
| $V_{SIH}$ | input high level    | 2   |      | 3.3 | V        |
| $V_{SIL}$ | Input low level     | 0   |      | 0.8 | V        |
| $V_{STH}$ | switching threshold |     | 1.65 |     | V        |
| $V_{ST}$  | termination voltage |     | 0    |     | V        |
| $Z_S$     | input impedance     |     | 1000 |     | $\Omega$ |

## Time Measurement Parameters

| Symbol | Parameter                                  | up to 7.x |     |     | 8.x and up |     |     | Units |
|--------|--|-----------|-----|-----|------------|-----|-----|-------|
|        |  | Min       | Typ | Max | Min        | Typ | Max |       |
|        | nominal bin size                           |           | 25  |     |            | 25  |     | ps    |
|        | stability over temperature (0°C to 85°C)   |           |     | 20  |            |     |     | ppm   |
|        | stability over temperature (-20°C to 70°C) |           |     |     |            |     | 1   | ppm   |
|        | aging first year                           |           |     | 5   |            |     | 1   | ppm/a |
|        | aging thereafter                           |           |     | 2   |            |     | 1   | ppm/a |
|        | initial frequency inaccuracy               |           |     |     |            |     | 4   | ppm   |
|        | peak to peak jitter                        |           | 25  |     |            |     |     | ps    |
|        | differential nonlinearity                  | -25       |     | 25  | -25        |     | 25  | ps    |
|        | integral nonlinearity                      | -25       |     | 25  | -25        |     | 25  | ps    |
|        | crosstalk (7 aggressors) <sup>1</sup>      |           |     | 150 |            |     | 150 | ps    |
|        | skew between channels <sup>1</sup>         |           |     | 2.4 |            |     | 2.4 | ns    |

1)Not tested.

## Data Rate

In order to guarantee that absolutely no hits are lost during data acquisition, the following hit counts must not be exceeded. In many cases exceeding these values will result only in a small amount of lost hits depending on the pattern of the arriving hits.

| Symbol              | Scope  | Number of Hits | Timeframe |
|---------------------|--|----------------|-----------|
| Hcrit <sub>1</sub>  | highres channel <sup>1</sup>                         | 1              | 10ns      |
| Hcrit <sub>2a</sub> | highres channel <sup>1,4</sup><br>(25ps resolution)  | 2              | 400ns     |
| Hcrit <sub>2b</sub> | highres channel <sup>1,4</sup><br>(100ps resolution) | 2              | 100ns     |
| Hcrit <sub>3a</sub> | highres channel <sup>1,5</sup><br>(25ps resolution)  | 4              | 400ns     |
| Hcrit <sub>3b</sub> | highres channel <sup>1,5</sup><br>(100ps resolution) | 4              | 100ns     |
| Hcrit <sub>4</sub>  | highres channel pair <sup>2</sup>                    | 256            | 25us      |
| Hcrit <sub>4</sub>  | all highres channels <sup>2</sup>                    | 512            | 8us       |
| Lcrit <sub>1</sub>  | lowres channel <sup>1</sup>                          | 1              | 30ns      |
| Lcrit <sub>2</sub>  | lowres channel <sup>1</sup>                          | 16             | 800ns     |
| Lcrit <sub>3</sub>  | all channels <sup>3</sup>                            | 2000           | 500us     |

- 1) Hits lost as these constraints are not met cannot be detected by hardware.
- 2) Hits lost due to these constraints are reported as errors in the datastream. The exact number of lost hits cannot be detected.
- 3) Hits lost due to these constraints are reported with the exact number of lost hits. The number of lost hits is reported separately for trigger channels.
- 4) This criterion applies when rising edge is enabled for at least one hires channel and falling edge is enable for at least one hires channel. This might be the same or a different channel. Up to driver version 3.0.0 inclusive this rule included lores channels.
- 5) This relaxed criterion applies when no hires channels uses rising edges or no hires channels uses falling edges. Up to driver version 3.0.0 inclusive this rule included lores channels.

## System Integration

The devices are not ready to use as delivered by cronologic. It requires the development of specialized software to fulfill the application of the end user. The device is provided to system integrators to be built into measurement systems that are distributed to end users. These systems usually consist of a the HPTDC, a main board, a case, application software and possible additional electronics to attach the system to some type of detector. They might also be integrated with the detector.

The HPTDC8-PCI, HPTDC-MDS and HPTDC-MDS-RoHS are designed to comply with DIN EN 61326-1 when operated on a PCI compliant main board housed in a properly shielded enclosure. When operated in a closed standard compliant PC enclosure the device does not pose any hazards as defined by EN 61010-1.

Radiated emissions, noise immunity and safety highly depend on the quality of the enclosure. It is the responsibility of the system integrator to ensure that the assembled system is compliant to applicable standards of the country that the system is operated in, especially with regards to user safety and electromagnetic interference. Compliance was only tested for attached cables shorter than 3m.

The HPTDC-Chip of HPTDC8-PCI and HPTDC-MDS contains up to 1g of lead. It is the responsibility of the system integrator to check whether the resulting system will comply to or is exempt from ROHS regulations such as EU directive 2011/65/EU.

The HPTDC-MDS-RoHS complies with the directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment 2011/65/EU (ROHS).

## Recycling

Cronologic is registered with the „Stiftung Elektro-Altgeräte Register“ as a manufacturer of electronic systems with Registration ID DE 77895909.

The HPTC belongs to category 9, „Überwachungs und Kontrollinstrumente für ausschließlich gewerblich Nutzung“. The last owner of a HPTDC must recycle or treat the board in compliance with §11 and §12 of the german ElektroG or return it to cronologic:

cronologic GmbH & Co. KG  
Jahnstraße 49  
D-60318 Frankfurt

## Contact and Updates

Driver updates can be downloaded from the HPTDC product page at:

<http://www.cronologic.de/>

For technical questions please send an E-Mail to

[hptdc@cronologic.de](mailto:hptdc@cronologic.de)