FMC TDC 1ns 5 Channel Documentation

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ONE

INTRODUCTION

This document describes the gateware developed to support the FmcTDC 1n 5channel (later refered to as fmc-tdc) mezzanine card on the SPEC and SVEC carrier cards. The gateware is the HDL code used to generate the bitstream that configures the FPGA on the carrier (sometimes also called firmware). The gateware architecture is described in detail. The configuration and operation of the fmc-tdc is also explained. The Linux driver and basic tools are explained as well. On the other hand, this manual is not intended to provide information about the hardware design.

1.1 Repositories and Releases

The FMC TDC 1ns 5 Channels is hosted on the Open HardWare Repository. The main development happens here. You can clone the GIT project with the following command:

```
git clone https://ohwr.org/project/fmc-tdc.git
```

Within the GIT respository, releases are marked with a TAG named using the Semantic Versioning. For example the latest release is `v8.0.0`. You can also find older releases with a different versioning mechanism.

For each release we will publish the FPGA bitstream for all supported carrier cards (FPGA Bitstream Page). For the Linux driver we can't release the binary because it depends on the Linux version on which it will run. For details about how to build the Linux driver for your kernel please have a look at *Compile And Install* section in *Driver's Documentation*.

1.2 Documentation License

CHAPTER

TWO

HARDWARE DESCRIPTION

The *FmcTdc* is an FPGA Mezzanine Card (FMC - VITA 57 standard), containing a 5-channel Time To Digital Converter (TDC). All channels share same time base, therefore one can relate timestamps of pulses coming to different channels.

2.1 Requirements and Supported Platforms

FmcTdc can work with any VITA 57-compliant FMC carrier, provided that the carrier's FPGA has enough logic resources. This release of the driver software supports the following carriers:

- SPEC (Simple PCI-Express Carrier),
- SVEC (Simple VME64x Carrier)

In order to operate *FmcTdc*, the following hardware/software components are required:

- A standard PC with at least one free 4x (or wider) PCI-Express slot and a SPEC PCI-Express FMC carrier (supplied with an FmcTdc),
- In case of a VME version: any VME64x crate with a controller (tested on a MEN A20 and MEN A25) and a SVEC VME64x FMC carrier (supplied with one or two *FmcTdcs*),
- 50-ohm cables with 1-pin LEMO 00 plugs for connecting the I/O signals,
- Any Linux (kernel 3.10+) distribution.

2.2 Mechanical/Environmental

Mechanical and environmental specification:

- Format: FMC (VITA 57),
- Operating temperature range: 0 - 90 degC,
- Carrier connection: 160-pin Low Pin Count FMC connector.

Electrical Inputs/Outputs:

- 5 trigger inputs (LEMO 00),
- 6 LEDs: 5 for indicating input pulse, 1 as an PPS indicator,
- Carrier communication via 160-pin Low Pin Count FMC connector.

Trigger input:

- TTL/LVTTL levels, DC-coupled,

- 2 kOhm or 50 Ohm input impedance (software-selectable),
- Power-up input impedance: 2 kOhm,
- Protected against short circuit, overcurrent (> 200 mA) and overvoltage (up to +15 V),
- Maximum input pulse edge rise time: 20 ns.

Power supply:

- Used power supplies: P12V0, P3V3, P3V3 AUX, VADJ (voltage monitor only).
- Typical current consumption: FIXME (P12V0) + FIXME (P3V3).
- Power dissipation: [fixme: Eva] W

2.3 Timing

Time base:

- On-board oscillator accuracy: +/- 4 ppm (i.e. max. 4 ns error for pulses separated by 1 ms).
- When using White Rabbit as the timing reference: depending on the characteristics of the grandmaster clock and the carrier used. Usually < 1ns.

Input timing:

- Minimum pulse width: 100 ns. Pulses below 100 ns are rejected. Width checking is done in software by subtracting rising and falling edge timestamps.
- Minimum pulse spacing: 100 ns.
- Only rising edges are time tagged.
- TDC precision: 700 ps peak-peak (six sigma). Outliers of ± 4 ns are observed at the expected frequency of ~ 1 outlier/10M measurements.
- TDC resolution: 81 ps.

CHAPTER

THREE

THE GATEWARE

3.1 About Source Code

3.1.1 Build from Sources

The fmc-tdc hdl design make use of the `hdlmake` tool. It automatically fetches the required hdl cores and libraries. It also generates Makefiles for synthesis/par and simulation.

Here is the procedure to build the FPGA binary image from the hdl source.:

```
# Install ``hdlmake`` (version 3.4).
# Get fmc-tdc hdl sources.
git clone https://ohwr.org/project/fmc-tdc.git <src_dir>

# Goto the synthesis directory.
cd <src_dir>/hdl/syn/<carrier>/

# Fetch the dependencies and generate a synthesis Makefile.
hdlmake

# Perform synthesis, place, route and generate FPGA bitstream.
make
```

3.1.2 Source Code Organisation

hdl/rtl/ TDC specific hdl sources.

hdl/ip_cores/ Location of fetched hdl cores and libraries.

hdl/top/<design> Top-level hdl module for selected design.

hdl/syn/<design> Synthesis directory for selected design. This is where the synthesis top manifest, the design constraints and the ISE project are stored. For each release, the synthesis, place&route and timing reports are also saved here.

hdl/testbench/ Simulation files and testbenches.

3.1.3 Dependencies

The fmc-tdc gateware depends on the following hdl cores and libraries: General Cores, DDR3 SP6 core, GN4124 core (SPEC only), SPEC (SPEC only) VME64x Slave (SVEC only), SVEC (SVEC only), WR Cores.

These dependencies are managed with GIT submodules. Whenever you checkout a different branch remember to update the submodules as well.:

```
git submodule sync
git submodule update
```

3.2 DATA FORMAT

The TDC gateware is retrieving timestamps generated by the ACAM chip, it is adapting them to a comprehensive format and it is then making them available to the PCIe interface in a circular buffer. Each final timestamp is a 128-bit word with the following structure:

Bits	Description
[127:96]	Metadata
	[127..125]: Input Channel from 0 to 4
	[123] : Edge Type, “1” means rising edge, “0” means falling
	[122..96] : not used
[95:64]	Local UTC time: the resolution is 1 s
[63:32]	Coarse time within the current UTC time: the resolution is 8 ns
[31:0]	Fine time: the resolution is 81.03 ps

As the structure indicates, each timestamp is referred to a UTC second. The coarse and fine times indicate with 81.03 ps resolution the amount of time passed after the last UTC second.

CHAPTER

FOUR

THE SOFTWARE

4.1 Driver

4.1.1 Driver Features

4.1.2 Requirements

The fmc-tdc device driver has been developed and tested on Linux 3.10. Other Linux versions might work as well but it is not guaranteed.

This driver depends on the zio framework and fmc library; we developed and tested against version zio 1.4 and fmc 1.1.

The FPGA address space must be visible on the host system. This requires a driver for the FPGA carrier that exports the FPGA address space to the host. As of today we support SPEC and SVEC.

4.1.3 Compile And Install

The compile and install the fmctdc1ns5ch device driver you need first to export the path to its direct dependencies, and then you execute `make`. This driver depends on the zio framework and fmc library; on a VME system it depends also on the VME bridge driver from CERN BE-CEM. Additionally it is assumed that location of wbgen2 is available via `PATH` variable.

```
$ cd /path/to/fmc-tdc/software/kernel
$ export LINUX=/path/to/linux/sources
$ export ZIO=/path/to/zio
$ export FMC=/path/to/fmc-sw
$ export VMEBUS=/path/to/vmebridge
$ make
$ make install
```

Note: Since version v8.0.0 the fmc-tdc device driver does not depend anymore on fmc-bus subsystem, instead it uses a new fmc library

The building process generates 3 Linux modules: *kernel/fmc-tdc.ko*, *kernel/fmc-tdc-spec.ko* (for SPEC card), and *kernel/fmc-tdc-svec.ko* (for SVEC card).

4.1.4 Drivers' Dependencies

The TDC driver requires the following drivers to function:

- if the used carrier is SPEC then from spec repository: *gn412x-fcl.ko*, *gn412x-gpio.ko*, *spec-gn412x-dma.ko* and *spec-fmc-carrier.ko*
- if the used carrier is SVEC then *vmebus.ko*
- from general-cores repository: *spi-ocores.ko*, *i2c-ocores.ko* and *htvic.ko* (more details in the section *Building General Cores drivers*)
- from zio repository: *zio-buf-vmalloc.ko* and *zio.ko* (more details in the section *Building ZIO drivers*)
- from fmc repository: *fmc.ko* (more details in the section *Building FMC driver*)
- drivers from the kernel tree: *mtd.ko*, *at24.ko*, *m25p80.ko*, *i2c_mux.ko* and *fpga-mgr.ko* (available in kernels v4.4 and newer, for older kernels see section *Building FPGA manager driver*)

In addition the following tools are required to build above drivers:

- cheby (more details in the section *Installing Cheby*)
- wbgen2 (more details in the section *Installing Wbgen2*)

Please read the following subsections for details

4.1.5 Building Drivers

This subsection describes the build process of Linux Device Drivers used by the TDC and tools needed during their build.

Installing Cheby

Clone *cheby* repository:

```
$ git clone https://gitlab.cern.ch/cohtdrivers/cheby.git
```

Install cheby:

```
$ cd cheby
$ python setup.py install
```

It may be required to install *python-setuptools* or *python-setuptools.noarch* package using your Linux distribution's software manager.

Installing Wbgen2

Clone *wbgen2* repository:

```
$ git clone https://ohwr.org/project/wishbone-gen.git
```

If needed export the location of *wbgen2* (needed for *fmc-tdc* drivers compilation):

```
export WBGEN2=/path/to/wishbone-gen/wbgen2
```

Building FPGA Manager driver

If kernel module *fpga-mgr.ko* is not available in the kernel that is used, probably the backported version is needed.

Clone backported *fpga-manager* repository:

```
$ git clone https://gitlab.cern.ch/coht/fpga-manager.git
```

Build and install kernel module (*fpga-mgr.ko*):

```
$ cd fpga-manager
$ export LINUX=/path/to/linux/sources
$ make
$ make install
```

Building ZIO drivers

Clone *zio* repository:

```
$ git clone https://ohwr.org/misc/zio.git
```

Build and install kernel modules (*zio-buf-vmalloc.ko* and *zio.ko*):

```
$ cd zio
$ export LINUX=/path/to/linux/sources
$ make
$ make install
```

Building General cores drivers

Clone *general-cores* repository:

```
$ git clone https://ohwr.org/project/general-cores.git
```

Build and install kernel modules (*spi-ocores.ko*, *i2c-ocores.ko* and *htvic.ko*):

```
$ cd general-cores/software
$ export LINUX=/path/to/linux/sources
$ make
$ make install
```

Building FMC driver

Clone *fmc* repository:

```
$ git clone https://ohwr.org/project/fmc-sw.git
```

Build and install kernel module (*fmc.ko*):

$ cd fmc-sw/ $ export LINUX=/path/to/linux/sources $ make $ make install

Building SPEC drivers

Clone *spec* repository:

```
$ git clone https://ohwr.org/project/spec.git
```

Build and install kernel modules (*gn412x-fcl.ko*, *gn412x-gpio.ko*, *spec-gn412x-dma.ko* and *spec-fmc-carrier.ko*):

```
$ cd spec/software
$ export CHEBY=/path/to/cheby/bin/cheby
$ export I2C=/path/to/general-cores/software/i2c-ocores
$ export SPI=/path/to/general-cores/software/spi-ocores
$ export FPGA_MGR=/path/to/fpga-manager
$ export FMC=/path/to/fmc-sw
$ export LINUX=/path/to/linux/sources
$ make
$ make install
```

Building SVEC drivers

Building missing mainline drivers

It may happen that your system lacks of drivers that are included into the mainline Linux kernel. This section describes how to build *i2c-mux.ko* and *m25p80.ko* drivers for CENTOS 7.

The first step is to download the Linux sources that mach the version used in your system and unpack them using your favorite method. Then prepare sources for a compilation:

:: make prepare

Select missing drivers by adding `CONFIG_I2C_MUX=m` and `CONFIG_MTD_M25P80=m` to .config manually, or with a favorite tool (like `menuconfig`. Start the build of missing drivers:

```
make M=drivers/i2c/
make M=drivers/mtd/devices/
```

Copy drivers from `drivers/mtd/devices/m25p80.ko` and `drivers/i2c/i2c-mux.ko` to a known place.

4.1.6 Top Level Driver

The fmc-tdc is a generic driver for an FPGA device that could be instanciated on a number of FMC carriers. For each carrier we write a little Linux module which acts as a top level driver (like the MFD drivers in the Linux kernel). In these modules there is the knowledge about the virtual memory range, the IRQ lines, and the DMA engine to be used.

The top level driver is a platform driver that matches a string containing the application identifier. The carrier driver builds this identification string from the device ID embedded into the FPGA (https://ohwr.org/project/fpga-dev-id).

4.1.7 Loading drivers for SPEC

Load drivers *at24.ko* and *mtd.ko*. They should be distributed with your Linux distribution in package like `kernel-plus` for CENTOS 7 of `linux-modules` for Ubuntu.

```
sudo modprobe at24
sudo modprobe mtd
```

Load drivers from the mainline Linux:

```
sudo insmod i2c-mux.ko
sudo insmod m25p80.ko
```

Load *fmc* drivers:

```
sudo insmod fmc.ko
```

Load *fpga-manager* drivers:

```
sudo insmod fpga-mgr.ko
```

Load drivers from *general-cores*:

```
sudo insmod htvic.ko
sudo insmod i2c-ocores.ko
sudo insmod spi-ocores.ko
```

Load drivers from *spec-sw*:

```
sudo insmod spec-gn412x-dma.ko
sudo insmod gn412x-gpio.ko
sudo insmod gn412x-fcl.ko
sudo insmod spec-fmc-carrier.ko
```

If you use the custom path to the firmware, set it at the latest at this point.

```
echo -n <path_to_bitstreams> | sudo tee /sys/module/firmware_class/parameters/path
```

Load bitstream into SPEC's FPGA:

```
echo -n <bitstream.bin> | sudo tee /sys/kernel/debug/<PCIe_device>/fpga_firmware
```

Load the ZIO and TDC drivers:

```
sudo insmod zio.ko
sudo insmod zio-buf-vmalloc.ko
sudo insmod fmc-tdc.ko
sudo insmod fmc-tdc-spec.ko
```

4.1.8 Loading drivers for SVEC

For SVEC the loading procedure is very similar to SPEC. It is required to load *svec-fmc-carrier.ko* and *fmc-tdc-svec.ko* instead of *spec-fmc-carrier.ko* and *fmc-tdc-spec.ko*. Additionally, there is no need to load *spec-gn412x-dma.ko*, *gn412x-gpio.ko* and *gn412x-fcl.ko*, since these drivers are specific to SPEC.

```
sudo modprobe at24
sudo modprobe mtd
sudo insmod i2c-mux.ko
sudo insmod m25p80.ko
sudo insmod fmc.ko
sudo insmod fpga-mgr.ko
sudo insmod htvic.ko
sudo insmod i2c-ocores.ko
sudo insmod spi-ocores.ko
```

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```
sudo insmod svec-fmc-carrier.ko
echo -n <path_to_bitstreams> | sudo tee /sys/module/firmware_class/parameters/path
echo -n <bitstream.bin> | sudo tee /sys/kernel/debug/svec-vme.<slot>/fpga_firmware
sudo insmod zio.ko
sudo insmod zio-buf-vmalloc.ko
sudo insmod fmc-tdc.ko
sudo insmod fmc-tdc-svec.ko
```

4.1.9 Module Parameters

The driver accepts a few load-time parameters for configuration. You can pass them to insmod directly, or write them in `/etc/modules.conf` or the proper file in `/etc/modutils/`.

The following parameters are used:

irq_timeout_ms=NUMBER It sets the IRQ coalesing timeout expressed in milli-seconds (ms). By default the value is set to 10ms.

test_data_period=NUMBER It sets how many fake timestamps to generate every seconds on the first channel, 0 to disable. By default the value is set to 0.

dma_buf_ddr_burst_size=NUMBER It sets DDR size coalesing timeout expressed in number of timestamps. By default the value is set to 16 timestamps.

wr_offset_fix=NUMBER It overwrites the White-Rabbit calibration offset for calibration value computed before 2018. By default this is set to 229460 ps.

4.1.10 Device Abstraction

This driver is based on the ZIO framework. It supports initial setup of the board; it allows users to manually configure the board, to start and stop acquisitions, to force trigger, and to read all the acquired time-stamps.

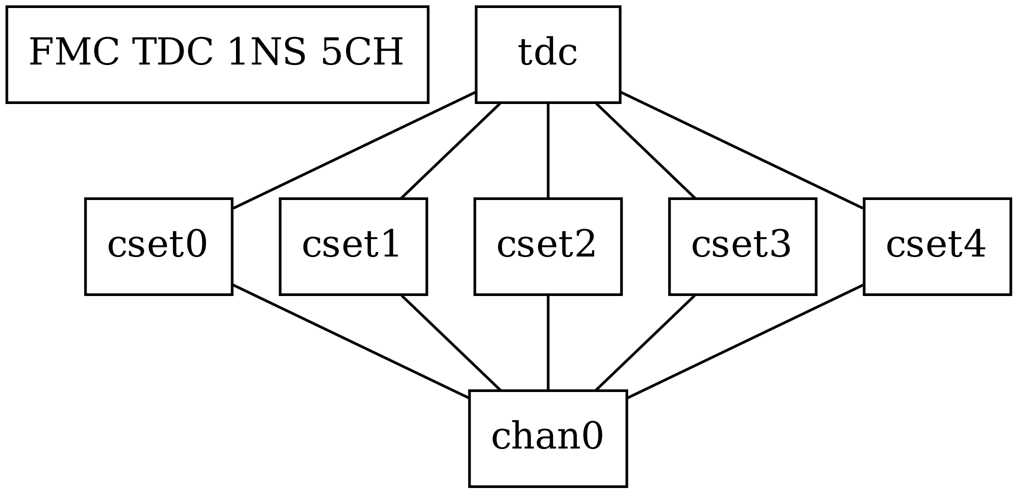
The driver is designed as a ZIO driver. ZIO is a framework for input/output hosted on http://www.ohwr.org/projects/zio.

ZIO devices are organized as csets (channel sets), and each of them includes channels. All channels belonging to the same cset trigger together. This device offers a channel-set for each channel.

Note: Unless specified, the units are the same as for the TDC HDL design. Therefore, this driver does not perform any data processing.

The Overall Device

As said, the device has 5 cset with 1 channel each. Channel sets from 0 to 4 represent the physical channels 1 to 5. In other words a channel set represents a single TDC channel.



The TDC registers can be accessed in the proper sysfs directory:

```
cd /sys/bus/zio/devices/tdc-1n5c-${ID}
```

The overall device (*tdc-1n5c*) provides the following attributes:

calibration_data It is a binary attribute which allows the user to change the run-time calibration data (the EEPROM will not be touched). The `fmc-tdc-calibration` tool can be used to read write calibration data. To be consistent, this binary interface expects **only** little endian values because this is the endianness used to store calibration data for this device.

coarse Coarse part of the current TAI time. This value is in nanoseconds with 8 ns resolution. The `fmc-tdc-time` tool can be used to read TAI time.

command Send the command to the driver. As today it is possible to enable/disable White Rabbit, set the board to the current time or check the source of the timing. The `fmc-tdc-time` tool can be used to send the commands related to the current time source.

seconds Current TAI time in seconds. The `fmc-tdc-time` tool can be used to read TAI time.

temperature It shows the current temperature. To get the temperature in C degrees use the formula `temperature/16`. The `fmc-tdc-temperature` tool can be used to read the temperature.

transfer-mode It shows the current transfer mode. 0 for FIFO, 1 for DMA.

wr-offset Offset used by White Rabbit.

The Channel Set

The TDC has 5 Channel Sets named `cset[0-4]`. Its attributes are used to control and monitor each TDC channel individually. All channel specific attributes are available at the channel set level.

The Channels

Because there is a one-to-one relation with the channel set, we have decided to put all custom attributes at the channel set level. So, at this level you will find only default ZIO attributes.

The Trigger

TODO fix this section

In ZIO, the trigger is a separate software module, that can be replaced at run time. This driver includes its own ZIO trigger type, that is selected by default when the driver is initialized. You can change trigger type (for example use the timer ZIO trigger) but this is not the typical use case for this board.

This is the list of attributes (excluding kernel-generic and ZIO-generic ones):

enable This is a standard zio attribute, and the code uses it to enable or disable the hardware trigger (i.e. internal and external). By default the trigger is enabled.

post-samples, pre-samples Number of samples to acquire. The pre-samples are acquired before the actual trigger event (plus its optional delay). The post samples start from the trigger-sample itself. The total number of samples acquired corresponds to the sum of the two numbers. For multi-shot acquisition, each shot acquires that many sample, but pre + post must be at most 2048.

The Buffer

TODO fix this section

In ZIO, buffers are separate objects. The framework offers two buffer types: kmalloc and vmalloc. The former uses the kmalloc function to allocate each block, the latter uses vmalloc to allocate the whole data area. While the kmalloc buffer is linked with the core ZIO kernel module, vmalloc is a separate module. The driver currently prefers kmalloc, but even when it preferred vmalloc (up to mid June 2013), if the respective module was not loaded, ZIO would instantiate kmalloc.

You can change the buffer type, while not acquiring, by writing its name to the proper attribute. For example:

```
echo vmalloc > /sys/bus/zio/devices/tdc-1n5c-0004/cset0/current_buffer
```

The disadvantage of kmalloc is that each block is limited in size. usually 128kB (but current kernels allows up to 4MB blocks). The bigger the block the more likely allocation fails. If you make a multi-shot acquisition you need to ensure the buffer can fit enough blocks, and the buffer size is defined for each buffer instance, i.e. for each channel. In this case we acquire only from the interleaved channel, so before making a 1000-long multishot acquisition you can do:

```
export DEV=/sys/bus/zio/devices/tdc-1n5c-0004
echo 1000 > $DEV/cset0/chani/buffer/max-buffer-len
```

The vmalloc buffer allows mmap support, so when using vmalloc you can save a copy of your data (actually, you save it automatically if you use the library calls to allocate and fill the user-space buffer). However, a vmalloc buffer allocates the whole data space at the beginning, which may be unsuitable if you have several cards and acquire from one of them at a time.

The vmalloc buffer type starts off with a size of 128kB, but you can change it (while not acquiring), by writing to the associated attribute of the interleaved channel. For example this sets it to 10MB:

```
export DEV=/sys/bus/zio/devices/tdc-1n5c-0004
echo 10000 > $DEV/cset0/chani/buffer/max-buffer-kb
```

4.1.11 The debugfs Interface

When the DMA mode is used, the fmctdc1ns5cha driver exports a set of debugfs attributes which are supposed to be used only for debugging activities. For each device instance you will see a directory in `/sys/kernel/debug/fmc-tdc.*`.

regs It dumps the FPGA registers

4.1.12 Reading Data with Char Devices

To read data from user-space, applications should use the ZIO char device interface. ZIO creates 2 char devices for each channel (as documented in ZIO documentation). The TDC can acquire data on each channel independently, so ZIO creates ten char device, as shown below:

```
$ ls -l /dev/zio/tdc-*
  cr--r----- 1 root root 241, 0 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-0-0-ctrl
  cr--r----- 1 root root 241, 1 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-0-0-data
  cr--r----- 1 root root 241, 2 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-1-0-ctrl
  cr--r----- 1 root root 241, 3 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-1-0-data
  cr--r----- 1 root root 241, 4 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-2-0-ctrl
  cr--r----- 1 root root 241, 5 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-2-0-data
  cr--r----- 1 root root 241, 6 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-3-0-ctrl
  cr--r----- 1 root root 241, 7 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-3-0-data
  cr--r----- 1 root root 241, 8 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-4-0-ctrl
  cr--r----- 1 root root 241, 9 Jan 13 13:36 /dev/zio/tdc-1n5c-000b-4-0-data
```

If more than one board is probed for, you'll have more similar pairs of devices, differing in the dev_id field, i.e. the `000b` shown above. The dev_id field is assigned by the Linux kernel platform subsystem.

The char-device model of ZIO is documented in the ZIO manual; basically, the ctrl device returns metadata and the data device returns data. Items in there are strictly ordered, so you can read metadata and then the associated data, or read only data blocks and discard the associated metadata.

The `zio-dump` tool, part of the ZIO distribution, turns metadata and data into a meaningful grep-friendly text stream.

4.1.13 User Header Files

Both the kernel and the user make use of the same header file `fmc-tdc.h`. This because they need to share some data structure and constants use to interpret data and meta-data in the library or by an application

Troubleshooting

This chapter lists a few errors that may happen and how to deal with them.

Installation issue with modules_install

The command `sudo make modules_install` may place the modules in the wrong directory or fail with an error like:

```
make: *** /lib/modules/<kernel-version>/build: No such file or directory.
```

This happens when you compiled by setting `LINUX=` and your sudo is not propagating the environment to its child processes. In this case, you should run this command instead:

```
sudo make modules_install  LINUX=$LINUX
```

4.2 Tools

The driver is distributed with a few tools living in the `tools/` subdirectory, most of these tools use the fmc-tdc library. The programs are meant to provide examples about the use of the driver and library interface.

4.2.1 List TDC boards

The tool `fmc-tdc-list` is capable of listing the available boards in the system. Below is the output from the command on an example system with 3 SPEC boards, each populated with a TDC mezzanine.

```
$ fmc-tdc-list
FMC-TDC Device ID 0019
FMC-TDC Device ID 0018
FMC-TDC Device ID 0017
```

4.2.2 Termination Configuration

The tool `fmc-tdc-term` enables or disables the 50 Ohm termination of a given input channel. The listing below shows the run of `fmc-tdc-term` tool to get the current status of the 50 Ohm termination on the TDC board with an ID assigned to 4:

```
$ fmc-tdc-term 0x4
channel 0: 50 Ohm termination is off
channel 1: 50 Ohm termination is off
channel 2: 50 Ohm termination is off
channel 3: 50 Ohm termination is off
channel 4: 50 Ohm termination is off
```

To set the 50 Ohm termination e.g. on channel 0 on the TDC board with an ID assigned to 4 please execute the following command:

```
$ fmc-tdc-term 0x4 0 on
channel 0: 50 Ohm termination is on
```

4.2.3 Reading Temperature

The tool `fmc-tdc-temperature` allows to read the current temperature of the TDC board. The command below reads the temperature of the TDC board with an ID assigned to 4:

```
$ fmc-tdc-temperature 0x4
31.4 deg C
```

4.2.4 Getting And Setting Board Time

The tool `fmc-tdc-time` allows to read and switch the time source to White-Rabbit or local oscillator. The command below gets the information about the current time source:

```
$ fmc-tdc-time 0x4 get
WR Status: synchronized.
Current TAI time is 1647471357.000000000 s
```

In the example above, the time source has been set to White-Rabbit. To set the time source to the local oscillator:

```
$ fmc-tdc-time 0x4 local
# no output after the command is executed
```

To set the time source to the White-Rabbit:

```
$ fmc-tdc-time 0x4 wr
Locking the card to WR: ... locked!
```

4.2.5 Read Timestamps

The tool `fmc-tdc-tstamp` can print acquired timestamps. In the example below the tool prints 5 samples (`-s` parameter) from the channel 2 (`-c` parameter) on the board with the ID 0x19 (`-D` parameter).

```
fmc-tdc-tstamp -D 0x19 -c 2 -s 5
channel 2 | channel seq 0
    ts   0000041028s  590492339195ps
    diff 0000041028s  590492339195ps [0.000024 Hz]
channel 2 | channel seq 1
    ts   0000041028s  591492339023ps
    diff 0000000000s  000999999828ps [1000.001000 Hz]
channel 2 | channel seq 2
    ts   0000041028s  592492338931ps
    diff 0000000000s  000999999908ps [1000.001000 Hz]
channel 2 | channel seq 3
    ts   0000041028s  593492338597ps
    diff 0000000000s  000999999666ps [1000.001000 Hz]
channel 2 | channel seq 4
    ts   0000041028s  594492338425ps
    diff 0000000000s  000999999828ps [1000.001000 Hz]
```

4.2.6 User Offset Configuration

The tool `fmc-tdc-offset` sets or gets the user-offset applied to the incoming timestamps. The example below show that all offsets are set to 0 in an example setup.

```
$ fmc-tdc-offset 0x19
channel 0: 0 ps
channel 1: 0 ps
channel 2: 0 ps
channel 3: 0 ps
channel 4: 0 ps
```

4.2.7 Calibration Data

The tool `fmc-tdc-calibration` reads calibration data from a file that contains it in binary form and shows it on STDOUT in binary form or in human readable one (default). This could be used to change the TDC calibration data at runtime by redirecting the binary output of this program to the proper sysfs binary attribute. This tool expects all values to be little endian. Please note that the TDC driver supports only ps precision, but calibration data is typically stored with sub-picosecond precision. For this reason, according to your source, calibration values may disagree on the fs part.

The example below shows the read of calibration data:

```
$ fmc-tdc-calibration -f /sys/bus/zio/devices/tdc-1n5c-0004/calibration_data
Temperature: 47 C
White Rabbit Offset: 229460000 fs
Zero Offset
  ch1-ch2: -109000 fs
  ch2-ch3: 493000 fs
  ch3-ch4: 499000 fs
  ch4-ch5: 336000 fs
```

4.3 The Library

Here you can find all the information about the *fmc-tdc* API and the main library behaviour that you need to be aware of to write applications.

This document introduces the developers to the development with the TDC library. Here you can find an overview about the API, the rational behind it and examples of its usage. It is not the purpose of the document to describe the API details. The complete API is available in *the Library API* section.

Note: The TDC hardware design diverged into different buffering structures. One based on FIFOs for SVEC, and one based on double-buffering in DDR for SPEC. The API tries to provide the same user-experience, however this is not always possible. Functions having different behaviour are properly declaring it in their documentation.

Note: This document provides also snippet of code from *example.c*. This is only to show you an example, please avoid to blindly copy and paste.

4.3.1 Initialization and Cleanup

The library may keep internal information, so the application should call its initialization function `fmctdc_init()`. After use, it should call the exit function `fmctdc_exit()` to release any internal data.

Note: `fmctdc_exit()` is not mandatory, the operating system releases anything in any case – the library doesn't leave unexpected files in persistent storage.

These functions don't do anything at this point, but they may be implemented in later releases. For example, the library may scan the system and cache the list of peripheral cards found, to make later *open* calls faster. For this reason it is **recommended** to, at least, initialize and release the library before starting.

Following an example from the `example.c` code available under `tools`

```
        err = fmctdc_init();
        if (err)
                exit(EXIT_FAILURE);
```

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```
        err = use_fmctdc_library();
        if (err)
                exit(EXIT_FAILURE);
        fmctdc_exit(); /* optional, indeed in the error condition
                          we do not do it */
```

4.3.2 Error Reporting

Each library function returns values according to standard *libc* conventions: -1 or NULL (for functions returning `int` or pointers, resp.) is an error indication. When error happens, the *errno* variable is set appropriately.

The *errno* values can be standard Posix items like `EINVAL`, or library-specific values, for example `FMCTDC_ERR_VMALLOC` (*driver vmalloc allocator not available*). All library-specific error values have a value greater than 4096, to prevent collision with standard values. To convert such values to a string please use *fmctdc_strerror()*

Following an example from the `example.c` code available under `tools`

```
                fprintf(stderr, "%s: Cannot open device: %s\n",
                        prog_name, fmctdc_strerror(errno));
```

4.3.3 Opening and closing

Each device must be opened before use by calling *fmctdc_open()*, and it should be closed after use by calling *fmctdc_close()*.

Note: *fmctdc_close()* is not mandatory, but it is recommended, to close if the process is going to terminate, as the library has no persistent storage to clean up – but there may be persistent buffer storage allocated, and *fmctdc_close()* may release it in future versions.

The data structure returned by *fmctdc_open()* is an opaque pointer used as token to access the API functions. The user is not supposed to use or modify this pointer.

Another kind of open function has been provided to satisfy CERN's developers needs. Function *fmctdc_open_by_lun()* is the open by LUN (*Logic Unit Number*); here the LUN concept reflects the *CERN* one. The usage is exactly the same as *fmctdc_open()* only that it uses the LUN instead of the device ID.

No automatic action is taken by *fmctdc_open()*. Hence, you may want to flush the buffers before starting a new acquisition session. You can do this with *fmctdc_flush()*

```
        tdc = fmctdc_open(0x0000);
        if (!tdc) {
                fprintf(stderr, "%s: Cannot open device: %s\n",
                        prog_name, fmctdc_strerror(errno));
                return -1;
        }

        err = fmctdc_flush(tdc, channel);
        if (err)
                return err;

        err = config_and_acquire(tdc);
```

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```
        if (err) {
                fprintf(stderr, "%s: Error: %s\n",
                        prog_name, fmctdc_strerror(errno));
                return -1;
        }

        fmctdc_close(tdc);
```

4.3.4 Configuration and Status

The TDC configuration API is based on a number of getter and setter function for each option. These include: *termination*, *IRQ coalescing timeout*, *board time*, *white-rabbit*, *timestamp mode*.

The *termination* options allows you to set the 50 Ohm channel termination. You can use the following getter and setter: `fmctdc_get_termination()`, `fmctdc_set_termination()`.

```
        err = fmctdc_set_termination(tdc, channel, termination);
        if (err)
                return err;
        termination_rb = fmctdc_get_termination(tdc, channel);
        if (termination_rb < 0)
                return termination_rb;
```

The *IRQ coalescing timeout* option allows to force an IRQ when the timeout expire to inform the driver that there is at least one pending timestamp to be transfered. You can use the following getter and setter: `fmctdc_coalescing_timeout_get()`, `fmctdc_coalescing_timeout_set()`.

```
        err = fmctdc_coalescing_timeout_set(tdc, channel, coalescing_timeout);
        if (err)
                return err;
        err = fmctdc_coalescing_timeout_get(tdc, channel, &coalescing_timeout_rb);
        if (err)
                return err;
```

The TDC main functionality is to timestap incoming pulses. To assign a timestamp the board needs a time reference. This can be provided by the on-board clock, or by the more accurate white-rabbit network. You can enable or disable white-rabbit using `fmctdc_wr_mode()`. You can check the white-rabbit status with `fmctdc_check_wr_mode()`. When working with white-rabbit the time reference is handled by the white-rabbit network.

```
        err = fmctdc_wr_mode(tdc, wr_mode);
        if (err)
                return err;
        wr_mode_rb = fmctdc_check_wr_mode(tdc);
        if (wr_mode_rb < 0)
                return wr_mode_rb;
```

If you do not have white-rabbit connected to the TDC, or simply this is not what you want, then be sure to disable. When white-rabbit is disabled the TDC will use the on-board clock to keep a time reference. However, in this scenario the user is asked to set first the time using `fmctdc_set_time()` or `fmctdc_set_host_time()`.

```
        err = fmctdc_set_time(tdc, &time);
        if (err)
                return err;
```

Whater you are using white-rabbit or not, you can get the current board time with *fmctdc_get_time()*.

```
err = fmctdc_get_time(tdc, &time_rb);
if (err)
        return err;
```

Still about time, the user can add it's own offset without changing the timebase using *fmctdc_get_offset_user()* and *fmctdc_set_offset_user()*.

```
err = fmctdc_set_offset_user(tdc, channel, offset_user);
if (err)
        return err;
err = fmctdc_get_offset_user(tdc, channel, &offset_user_rb);
if (err)
        return err;
```

Finally, you can monitor the board temperature using *fmctdc_read_temperature()*, and pulse and timestamps statistics with *fmctdc_stats_recv_get()* and *fmctdc_stats_trans_get()*.

```
err = fmctdc_stats_recv_get(tdc, channel, &recv);
if (err)
        return err;
err = fmctdc_stats_trans_get(tdc, channel, &trans);
if (err)
        return err;
```

Note: If it can be useful there is one last status function in the API used to detect the transfer mode between the driver and the board. This function is *fmctdc_transfer_mode()*

Timestamp buffering has its own set of options. Buffering in hardware is fixed, it can't be configured, so what we are going to describe here is the Linux device driver buffering configuration. Because the TDC driver is based on ZIO, then you can choose the buffer allocator type. You can handle this option with the pair: *fmctdc_get_buffer_type()* and *fmctdc_set_buffer_type()*.

```
err = fmctdc_set_buffer_type(tdc, buffer_type);
if (err)
        return err;
buffer_type_rb = fmctdc_get_buffer_type(tdc);
if (buffer_type_rb < 0)
        return buffer_type_rb;
```

You can configure - and get - the buffer size (number of timestamps) with: *fmctdc_get_buffer_len()* and *fmctdc_set_buffer_len()*. Beware, that this function works only when using *FMCTDC_BUFFER_VMALLOC*.

```
err = fmctdc_set_buffer_len(tdc, channel, buffer_len);
if (err)
        return err;
buffer_len_rb = fmctdc_get_buffer_len(tdc, channel);
if (buffer_len_rb < 0)
        return buffer_len_rb;
```

Finally, you can select between to modes to handle buffer's overflows: *FMCTDC_BUFFER_CIRC* and *FMCTDC_BUFFER_FIFO*. The first will discard old timestamps to make space for the new ones, the latter will discard any new timestamp until the buffer get consumed. To configure this option you can use: *fmctdc_get_buffer_mode()* and *fmctdc_set_buffer_mode()*.

```
        err = fmctdc_set_buffer_mode(tdc, channel, buffer_mode);
        if (err)
                return err;
        buffer_mode_rb = fmctdc_get_buffer_mode(tdc, channel);
        if (buffer_mode_rb < 0)
                return buffer_mode_rb;
```

4.3.5 Acquisiton

Before actually being able to get timestamps, the TDC acquisition must be enabled. The acquisition can be *enabled* or *disabled* through its gateware using, respectivily, `fmctdc_channel_enable()` and `fmctdc_channel_disable()`.

```
        err = fmctdc_channel_enable(tdc, channel);
        if (err)
                return err;

        err = fetch_and_process(tdc);
        if (err)
                return err;

        err = fmctdc_channel_disable(tdc, channel);
        if (err)
                return err;
```

To read timestamps you may use functions `fmctdc_read()` and `fmctdc_fread()`. As the name may suggest, the first behaves like `read` and the second as `fread`.

```
        do {
                n = fmctdc_read(tdc, channel, ts, max, O_NONBLOCK);
        } while (n < 0 && errno == EAGAIN);
        if (n < 0)
                return n;
```

If you need to flush the buffer, you can use `fmctdc_flush()`.

```
        err = fmctdc_flush(tdc, channel);
        if (err)
                return err;
```

4.3.6 Timestamp Math

The TDC library API has functions to support timestamp math. They allow you to *add*, *subtract*, *normalize*, and *approximate*. These functions are: `fmctdc_ts_add()`, `fmctdc_ts_sub()`, `fmctdc_ts_norm()`, `fmctdc_ts_ps()`, and `fmctdc_ts_approx_ns()`.

4.4 The Library API

Defines

PRItsps
printf format for timestamps with pico-second resolution

PRItspsVAL (_ts)
printf value for timestamps with pico-second resolution

PRItswr
printf format for timestamps with White-Rabbit notation

PRItswrVAL (_ts)
printf value for timestamp with White-Rabbit notation

__FMCTDC_ERR_MIN

Enums

enum fmctdc_error_numbers
Values:

FMCTDC_ERR_VMALLOC = __FMCTDC_ERR_MIN

FMCTDC_ERR_UNKNOWN_BUFFER_TYPE

FMCTDC_ERR_NOT_CONSISTENT_BUFFER_TYPE

FMCTDC_ERR_VERSION_MISMATCH

__FMCTDC_ERR_MAX

enum fmctdc_channel
Enumeration for all TDC channels

Values:

FMCTDC_CH_1 = 0

FMCTDC_CH_2

FMCTDC_CH_3

FMCTDC_CH_4

FMCTDC_CH_5

FMCTDC_CH_LAST = *FMCTDC_CH_5*

FMCTDC_NUM_CHANNELS = 5

enum fmctdc_buffer_mode
Enumeration of all buffer modes

Values:

FMCTDC_BUFFER_FIFO = 0
FIFO policy: when buffer is full, new time-stamps will be dropped

FMCTDC_BUFFER_CIRC
circular buffer policy: when the buffer is full, old time-stamps will be overwritten by new ones

enum fmctdc_buffer_type
Enumeration of all buffer types

Values:

FMCTDC_BUFFER_KMALLOC = 0
kernel allocator: kmalloc

FMCTDC_BUFFER_VMALLOC
kernel allocator: vmalloc

enum fmctdc_channel_status
Enumeration for all possible status of a channel

Values:

FMCTDC_STATUS_DISABLE = 0
The cannel is disable

FMCTDC_STATUS_ENABLE
the channel is enable

enum ft_transfer_mode
Values:

FT_ACQ_TYPE_FIFO = 0

FT_ACQ_TYPE_DMA

enum fmctdc_ts_mode
Enumeration for all possible time-stmap mode

Values:

FMCTDC_TS_MODE_POST = 0
after post-processing

FMCTDC_TS_MODE_RAW
directly from ACAM chip. This should be used ONLY when debugging low level issues

Functions

const char ***fmctdc_strerror** (int *err*)
It returns the error message associated to the given error code

Parameters

- `err`: error code

int **fmctdc_init** (void)
Init the library. You must call this function before use any other library function.

Return 0 on success, otherwise -1 and errno is appropriately set

void **fmctdc_exit** (void)
It releases all the resources used by the library and allocated by fmctdc_init().

int **fmctdc_set_time** (**struct** fmctdc_board **b*, **const struct** *fmctdc_time* **t*)
It sets the TDC base-time according to the given time-stamp. Note that, for the time being, it sets only seconds. Note that, you can set the time only when the acquisition is disabled.

Return 0 on success, otherwise -1 and errno is set

Parameters

- `userb`: TDC board instance token
- `t`: time-stamp

int **fmctdc_get_time** (**struct** fmctdc_board **b*, **struct** *fmctdc_time* **t*)
It gets the base-time of a TDC device. Note that, for the time being, it gets only seconds.

Return 0 on success, otherwise -1 and errno is set

Parameters

- `userb`: TDC board instance token
- `t`: time-stamp

int **fmctdc_set_host_time** (**struct** fmctdc_board **b*)

It sets the TDC base-time according to the host time

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token

int **fmctdc_wr_mode** (**struct** fmctdc_board **b*, int *on*)

It enables/disables the WhiteRabbit timing system on a TDC device

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `on`: white-rabbit status to set

int **fmctdc_check_wr_mode** (**struct** fmctdc_board **b*)

It check the current status of the WhiteRabbit timing system on a TDC device

Return 0 if it properly works, -1 on error and errno is set appropriately.

- ENOLINK if it is not synchronized and
- ENODEV if it is not enabled

Parameters

- `userb`: TDC board instance token

float **fmctdc_read_temperature** (**struct** fmctdc_board **b*)

It reads the current temperature of a TDC device

Return temperature

Parameters

- `userb`: TDC board instance token

int **fmctdc_channel_status_set** (**struct** fmctdc_board **userb*, unsigned int *channel*, **enum** *fmctdc_channel_status status*)

The function enables/disables timestamp acquisition for the given channel.

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: channel to which we want change status
- `status`: enable status to set

int **fmctdc_channel_enable** (**struct** fmctdc_board **userb*, unsigned int *channel*)

It enables a given channel. NOTE: it is just a wrapper of fmctdc_channel_status_set()

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: channel to which we want change status

int **fmctdc_channel_disable**(**struct** fmctdc_board **userb*, unsigned int *channel*)
It disable a given channel. NOTE: it is just a wrapper of fmctdc_channel_status_set()

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: channel to which we want change status

int **fmctdc_channel_status_get**(**struct** fmctdc_board **userb*, unsigned int *channel*)
It gets the acquisition status of a TDC channel

Return the acquisition status (0 disabled, 1 enabled), otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: channel to which we want read the status

int **fmctdc_set_termination**(**struct** fmctdc_board **b*, unsigned int *channel*, int *enable*)
The function enables/disables the 50 Ohm termination of the given channel. Termination may be changed anytime.

Return 0 on success, otherwise a negative errno code is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: to use
- `on`: status of the termination to set

int **fmctdc_get_termination**(**struct** fmctdc_board **b*, unsigned int *channel*)
The function returns current temrmination status: 0 if the given channel is high-impedance and positive if it is 50 Ohm-terminated.

Return termination status, otherwise a negative errno code is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: to use

int **fmctdc_get_buffer_type**(**struct** fmctdc_board **userb*)
The function returns current buffer type: 0 for kmallo, 1 for vmalloc.

Return buffer type, otherwise a negative errno code is set appropriately

Parameters

- `userb`: TDC board instance token

int **fmctdc_set_buffer_type**(**struct** fmctdc_board **userb*, **enum** *fmctdc_buffer_type type*)
The function sets the buffer type for a device

Return 0 on success, otherwise a negative errno code is set appropriately

Parameters

- `userb`: TDC board instance token
- `type`: buffer type to use

int **fmctdc_get_buffer_mode** (**struct** fmctdc_board **userb*, unsigned int *channel*)

The function returns current buffer mode: 0 for FIFO, 1 for circular buffer.

Return buffer mode, otherwise a negative errno code is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: to use

int **fmctdc_set_buffer_mode** (**struct** fmctdc_board **userb*, unsigned int *channel*, **enum** *fmctdc_buffer_mode mode*)

The function sets the buffer mode for a channel

Return 0 on success, otherwise a negative errno code is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: to use
- `mode`: buffer mode to use

int **fmctdc_get_buffer_len** (**struct** fmctdc_board **userb*, unsigned int *channel*)

The function returns current driver buffer length (number of timestamps)

Return buffer lenght, otherwise a negative errno code is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: to use

int **fmctdc_set_buffer_len** (**struct** fmctdc_board **userb*, unsigned int *channel*, unsigned int *length*)

The function set the buffer length Internally, the buffer allocates memory in chunks of minimun 1KiB. This means, for example, that if you ask for 65 timestamp the buffer will allocate space for 128. This because 64 timestamps fit in 1KiB, to store 65 we need 2KiB (128 timestamps).

Return 0 on success, otherwise a negative errno code is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: to use
- `length`: maximum number of timestamps to store (min: 64)

NOTE: it works only with the VMALLOC allocator.

int **fmctdc_set_offset_user** (**struct** fmctdc_board **userb*, unsigned int *channel*, int32_t *offset*)

It sets the user offset to be applied on incoming timestamps. All the timestamps read from the driver (this means also from this library) will be already corrected using this offset.

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]
- `offset`: the number of pico-seconds to be added

int **fmctdc_get_offset_user** (**struct** fmctdc_board **userb*, unsigned int *channel*, int32_t **offset*)

It get the current user offset applied to the incoming timestamps

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]
- `offset`: the number of pico-seconds to be added

int **fmctdc_transfer_mode** (**struct** fmctdc_board **userb*, **enum** *ft_transfer_mode* **mode*)

It gets the current transfer mode

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `mode`: transfer mode

int **fmctdc_coalescing_timeout_set** (**struct** fmctdc_board **userb*, unsigned int *channel*, unsigned int *timeout_ms*)

It sets the coalescing timeout on a given channel It does not work per-channel for the following acquisition mechanism:

- FIFO (it will return the global IRQ coalescing timeout)

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]
- `timeout_ms`: ms timeout to trigger IRQ

int **fmctdc_coalescing_timeout_get** (**struct** fmctdc_board **userb*, unsigned int *channel*, unsigned int **timeout_ms*)

It gets the coalescing timeout from a given channel It does not work per-channel for the following acuqisition mechanism:

- FIFO: there is a global configuration for all channels

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]
- `timeout_ms`: ms timeout to trigger IRQ

int **fmctdc_ts_mode_set** (**struct** fmctdc_board **userb*, unsigned int *channel*, **enum** *fmctdc_ts_mode* *mode*)

It sets the timestamp mode

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]

- `mode`: time-stamp mode

int **fmctdc_ts_mode_get** (**struct** fmctdc_board **userb*, unsigned int *channel*, **enum** *fmctdc_ts_mode* **mode*)

It gets the timestamp mode

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]
- `mode`: time-stamp mode

struct fmctdc_board ***fmctdc_open** (int *dev_id*)

struct fmctdc_board ***fmctdc_open_by_lun** (int *lun*)

It opens one specific device by logical unit number (CERN/BE-CO-like). The function uses a symbolic link in /dev that points to the standard device. The link is created by the local installation procedure, and it allows to get the device id according to the LUN. Read also fmctdc_open() documentation.

Return an instance token, otherwise NULL and errno is appripriately set

Parameters

- `lun`: Logical Unit Number

int **fmctdc_close** (**struct** fmctdc_board **userb*)

It closes a TDC instance opened with fmctdc_open() or fmctdc_open_by_lun()

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token

int **fmctdc_fread** (**struct** fmctdc_board **b*, unsigned int *channel*, **struct** *fmctdc_time* **t*, int *n*)

this "fread" behaves like stdio: it reads all the samples. Read fmctdc_read() for more details about the function.

Return number of acquired time-stamps, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: channel to use
- `t`: array of time-stamps
- `n`: number of elements to save in the array

int **fmctdc_fileno_channel** (**struct** fmctdc_board **b*, unsigned int *channel*)

It get the file descriptor of a TDC channel. So, for example, you can poll(2) and select(2). Note that, the file descriptor is the file-descriptor of a ZIO control char-device.

Return a file descriptor, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: channel to use

int **fmctdc_read** (**struct** fmctdc_board **b*, unsigned int *channel*, **struct** *fmctdc_time* **t*, int *n*, int *flags*)

It reads a given number of time-stamps from the driver. It will wait at most once and return the number of samples that it received from a given input channel.

Timestamps are to the base time.

This "read" behaves like the system call and obeys O_NONBLOCK

Return number of acquired time-stamps, otherwise -1 and errno is set appropriately.

- EINVAL for invalid arguments
- EIO for invalid IO transfer
- EAGAIN if nothing ready to read in NONBLOCK mode

Parameters

- `userb`: TDC board instance token
- `channel`: channel to use [0, 4]
- `t`: array of time-stamps
- `n`: number of elements to save in the array
- `flags`: tune the behaviour of the function. O_NONBLOCK - do not block

int **fmctdc_flush** (**struct** fmctdc_board **userb*, unsigned int *channel*)

It removes all samples from the channel buffer. In order to doing this, the function temporary disable any active acquisition, only when the flush is completed the acquisition will be re-enabled

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]

int **fmctdc_stats_recv_get** (**struct** fmctdc_board **userb*, unsigned int *channel*, uint32_t **val*)

It gets the number of received pulses (on hardware)

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]
- `val`: number of received pulses

int **fmctdc_stats_trans_get** (**struct** fmctdc_board **userb*, unsigned int *channel*, uint32_t **val*)

It gets the number of transferred timestamps

Return 0 on success, otherwise -1 and errno is set appropriately

Parameters

- `userb`: TDC board instance token
- `channel`: target channel [0, 4]
- `val`: number of transferred timestamps

uint64_t **fmctdc_ts_approx_ns** (**struct** *fmctdc_time* **a*)

Set of mathematical functions on time-stamps

It provides a nano-second approximation of the timestamp.

Return it returns the time stamp in nano-seconds

Parameters

- a: timestamp

uint64_t **fmctdc_ts_ps** (**struct** *fmctdc_time* **a*)

It provides a pico-seconds representation of the time stamp. Bear in mind that it may overflow. If you thing that it may happen, check the timestamp

Return it returns the time stamp in pico-seconds

Parameters

- a: timestamp

void **fmctdc_ts_norm** (**struct** *fmctdc_time* **a*)

It normalizes the timestamp

Parameters

- a: timestamp

int **fmctdc_ts_sub** (**struct** *fmctdc_time* **r*, **const struct** *fmctdc_time* **a*, **const struct** *fmctdc_time* **b*)

It perform the subtraction: r = a - b

Return 1 if the difference is negative, otherwise 0

Parameters

- r: result
- a: normalized timestamp
- b: normalized timestamp

void **fmctdc_ts_add** (**struct** *fmctdc_time* **r*, **const struct** *fmctdc_time* **a*, **const struct** *fmctdc_time* **b*)

It perform an addiction: r = a + b

Parameters

- r: result
- a: normalized timestamp
- b: normalized timestamp

int **_fmctdc_tscmp** (**struct** *fmctdc_time* **a*, **struct** *fmctdc_time* **b*)

Variables

const char ***const libfmctdc_version_s**

libfmctdc version string

const char ***const libfmctdc_zio_version_s**

zio version string used during compilation of libfmctdc

struct fmctdc_time

#include <fmctdc-lib.h> FMC-TDC time-stamp descriptor

Public Members

uint64_t **seconds**

TAI seconds. Note this is *not* an UTC time; the counter does not support leap seconds. The internal counter is also limited to 32 bits (2038-error-prone).

uint32_t **coarse**
number of ticks of 8ns since the beginning of the last second

uint32_t **frac**
fractional part of an 8 ns tick, rescaled to (0..4095) range - i.e. 0 = 0 ns, and 4095 = 7.999 ns.

uint32_t **seq_id**
channel sequence number

uint32_t **debug**
debug stuff, driver/firmware-specific

CHAPTER

FIVE

THE MEMORY MAP

5.1 Supported Designs

Here you can find the complete memory MAP for the supported designs. This will include the TDC registers as well as the carrier registers and any other component used in an FMC-TDC-1NS-5CH design.

5.1.1 SPEC FMC-TDC-1NS-5CHA

The memory map is divided in two parts: the *Carrier (SPEC)* part common to all SPEC designs, and the *TDC* part specific to the FMC-TDC-1NS-5CHA mezzanine.

> **Warning:** Unfortunately we are not able to include the memory map in PDF format. Please for the memory map refer to the online documentation,

SPEC base registers

> **Warning:** Unfortunately we are not able to include the memory map in PDF format. Please for the memory map refer to the online documentation,

FMC-TDC-1NS-5CHA

See *TDC memory map*.

5.1.2 SVEC FMC-TDC-1NS-5CHA

The memory map is divided in two parts: the *Carrier (SVEC)* part common to all SVEC designs, and the *TDC1* and *TDC2* part specific to the FMC-TDC-1NS-5CHA mezzanine.

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SVEC base registers

> **Warning:** Unfortunatelly we are not able to include the memory map in PDF format. Please for the memory map refer to the online documentation,

First FMC-TDC-1NS-5CHA

See *TDC memory map*.

Second FMC-TDC-1NS-5CHA

See *TDC memory map*.

5.2 TDC memory map

Following the memory map for the part of the TDC design that drives the FMC-TDC-1NS-5CH modules.

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5.2.1 One wire

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5.2.2 Core

5.2.3 EIC

> **Warning:** Unfortunatelly we are not able to include the memory map in PDF format. Please for the memory map refer to the online documentation,

5.2.4 I2C

Not used.

5.2.5 Mem

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5.2.6 Mem DMA

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5.2.7 Mem DMA EIC

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