SPEC Software Support

Version 2.0 (September 2012)
A driver for the SPEC card and its FMC modules

Alessandro Rubini for CERN (BE-CO-HT)

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Introduction

This is the manual for the SPEC device driver. SPEC is the *Simple PCI-Express Carrier* for FMC cards, developed at http://www.ohwr.org/projects/spec. This manual is part of the associated software project, hosted at http://www.ohwr.org/projects/spec-sw. The latest version of this work is always available in the *git* repository at `ohwr.org`.

1 History and Overview

This driver is pretty different from the initial implementation, such as the one used by *fine-delay-sw-v1.1*. If you are using that version, please compile the manual you find in your source code repository and avoid reading this one.

The package currently includes both the *spec* driver and the *fmc* bus driver (documented separately). Moreover, it includes some drivers for fmc cards.

2 Compiling the Drivers

The kernel modules that are part of this package live in the *kernel* subdirectory. To compile them, you need to set the following variables in your environment:

`LINUX`
: The top directory of the kernel sources for the version you are going to run the driver under. I'm testing mostly with 3.4, but this version compiles against Linux-2.6.37 and later ones (2.6.36 had a different interface for hardware timestamping, so *fmc* and *spec* compile fine, but *wr-nic* does not).

`CROSS_COMPILE`
: If you are cross-compiling, you need to set this variable. It is not usually needed for the PC, but if you are using the *Powec* board, you'll most likely need this. It is not needed if you compile for a different-sized PC (see below).

`ARCH`
: If you are cross-compiling, set this variable. Use `powerpc` for the *Powec*, `x86-64` if you compile on a 32-bit PC to run on a 64-bit PC and `i386` if you compile on a 64-bit PC to run on a 32-bit PC.

To compile run "`make`" with the previous variables set. To install run "`make install` to install under `/lib/modules/3.4.0` (or other version-based directory). You can set `INSTALL_MOD_PATH` to force and installation directory (as a prefix followed by `/lib/modules/...`). For example, if your target computer's filesystem is mounted under `/mnt/target` you can run

```
make install INSTALL_MOD_PATH=/mnt/target
```

The modules are installed under the subdirectory `extra`. In the case shown above your driver will end up being installed (together with the other modules) as

```
/mnt/target/lib/modules/3.4.0/extra/spec.ko
```

3 Role of spec.ko

The `spec.ko` driver depends on `fmc.ko`, that must be loaded first (if you don't rely on automatic dependencies).

`spec.ko` registers as a PCI driver, using both the "old" identifiers (i.e. the Gennum vendor and GN4124 device) and the new ones (CERN vendor and SPEC device).

3.1 SPEC Initialization

For each new SPEC device found on the system, the driver performs the following steps:

- It enables MSI interrupts, the only ones supported in this package.
- It loads the `fmc/spec-init.bin` "golden" gateware file.
- It checks that the content of the binary is as expected (using a minimal *sdb*-based verification).
- It reads the whole I2C EEPROM found on the mezzanine.
- It allocates an *fmc_device* structure and registers as a new device in the *fmc* bus.

Failure of any of the above steps is fatal.

The suggested `spec-init.bin` gateware binary is always available from the *files* area of the *spec-sw* project on `ohwr.org`. The current binary version to be used with this software version is `http://www.ohwr.org/attachments/download/1454/spec-init.bin-2012-07-24`.

The EEPROM content that has been read at initialization time is still available to sub-drivers after they are loaded, but a sub-driver cannot write to the EEPROM using carrier methods. The carrier refuses to act on registers after the golden gateware is replaced by a new mezzanine-specific binary, which by definition is unknown to the carrier itself.

Note: currently the SPEC driver does not re-write the golden binary file when the sub-driver releases control of the card. This allows a further driver to make use of an existing binary, and may be useful during development.

3.2 SPEC Module Parameters

The module can receive the following parameters to customize its operation:

`test_irq`
: If not zero, this parameter requests to self-test interrupt generation, using the Gennum registers. This usually does not work on my host, for yet unknown reasons (and that's why it is disabled by default).

`i2c_dump`
: If not zero, this parameter requests to *printk* the content of the FMC eeprom, for diagnostic purposes.

`fw_name`
: This string parameter can be used to override the default name (`fmc/spec-init.bin`) for the initialization binary file.

Any mezzanine-specific action must be performed by the driver for the specific FMC card, including reprograming the FPGA with the final gateware file. Similarly, the *spec* driver is not concerned with programming the LM32 image, when it makes sense to. This is different from the role splitting in previous versions of the driver.

Note: the gateware binary is looked-for in */lib/firmware/fmc*, which is where all fmc-related external files are expected to live. That's because our own installations share firmware for COTS peripherals but mount a host-specific NFS subdirectory.

Please refer to the *fmc-bus* document for details about the overall design of the interactions of carriers and mezzanines.

Warning: currently the *match* function of the bus always returns success: the mezzanines I currently have for testing have no ID records written in their internal EEPROM, so I'm not able to setup the associated data structures and code. For this reason there is no *module_alias* support nor autoprobe of drivers: any *fmc* driver you load will drive all SPEC cards found on the system unless it limits itself through parameters (see below)

3.3 Sub-Module Parameters

Most of the FMC drivers, also called sub-modules, need the same set of kernel parameters, this package includes support to implement common parameters, by means of fields in the `fmc_driver` structure and simple macro definitions.

The parameters are carrier-specific, in that they rely on the *busid* concept, that varies among carriers (here it is a PCI bus-devfn number). Drivers for other carriers will most likely offer something similar but not identical to this; some code duplication is unavoidable.

This is the list of parameters, to see how they are used in sub-modules, please look at *spec-trivial.c*.

`busid=`

This is an array of integers, specifying the PCI bus and PCI devfn, each of the fields being 8 bits (and the latter is most likely 0). For example: `0x0400` (bus 4, slot 0). If any such ID is specified, the sub-driver will only accept to drive cards that appear in the list (even if the FMC ID matches).

`gateware=`

The argument is an array of strings. If no *busid=* is specified, the first string of *gateware=* is used for all cards; otherwise the identifiers and gateware names are paired one by one, in the order specified.

For example, if you are using the trivial driver to load two different gateware files to two different cards, you can use the following parameters to load different binaries to the cards, after looking up the PCI identifiers:

```
insmod fmc-trivial.ko \
                      busid=0x0200,0x0400 \
                      gateware=fmc/fine-delay.bin,fmc/simple-dio.bin
```

Please note that not all sub-modules support all of those parameters. You can use *modinfo* to check what is supported by each module.

4 fmc-trivial.ko

The simple module *fmc-trivial* is just a simple client that registers an interrupt handler. I used it to verify the basic mechanism of the FMC bus and how interrupts worked.

The module implements the generic SPEC parameters, so it can program a different gateware file in each card. The whole list of parameters it accepts are:

`busid=`
`gateware=`

Generic parameters. See Section 3.3 [Sub-Module Parameters], page 3.

This driver is worth reading, but it is not worth describing here.

5 fmc-write-eeprom.ko

This module is designed to load a binary file from */lib/firmware* and to write it to the internal EEPROM of the mezzanine card. This driver uses the `busid` generic parameter, but doesn't use the other ones (even if *modinfo* reports them).

Overwriting the EEPROM is not something you should do daily, and it is expected to only happen during manufacturing. For this reason, the module makes it unlikely for the random user to change a working EEPROM.

The module takes the following measures:

- It accepts a `file=` argument (within */lib/firmware*) and if no such argument is received, it doesn't write anything (i.e. there is no default file name)
- If the file name ends with `.bin` it is written verbatim starting at offset 0.
- If the file name ends with `.tlv` it is interpreted as type-length-value (i.e., it allows *writev(2)*-like operation).
- If the file name doesn't match any of the patterns above, it is ignored and no write is performed.
- Only cards listed with `busid=` are written to. If no *busid* is specified, no programming is done (and the probe function of the driver will fail).

Each TLV tuple is formatted in this way: the header is 5 bytes, followed by data. The first byte is `w` for *write*, the next two bytes represent the address, in little-endian byte order, and the next two represent the data length, in little-endian order. The length does not include the header (it is the actual number of bytes to be written).

This is a real example: that writes 5 bytes at position 0x110:

```
spusa.root# od -t x1 -Ax /lib/firmware/try.tlv
000000 77 10 01 05 00 30 31 32 33 34
00000a
spusa.root# insmod /tmp/fmc-write-eeprom.ko busid=0x0200 file=try.tlv
[19983.391498] spec 0000:03:00.0: write 5 bytes at 0x0110
[19983.414615] spec 0000:03:00.0: write_eeprom: success
```

Please note that you'll most likely want to use SDBFS to build your EEPROM image, at least if your mezzanines are being used in the White Rabbit environment. For this reason the TLV format is not expected to be used much and is not expected to be developed further.

6 The WR-NIC

With the current code base, the `wr-nic.ko` driver is designed to run with the simple 5-Channel *simple-DIO* mezzanine board, because it includes both code to access the network card and code to act on the DIO channels, using time tags that are provided by the *White Rabbit* mechanism. Similarly, both incoming and outgoing frames can be time-stamped by *White Rabbit*.

This driver is the most important driver in this package: it is a generic implementation of the *spec-sw* framework which can be useful by itself as a White Rabbit starter kit. Moreover, it is a complete driver that can serve as a model for other developments.

Within *White Rabbit* we have other full-featured drivers for specialized FMC mezzanines hosted on the SPEC carrier. They are not part of this package because of their specialized nature; all of them are nonetheless hosted on `www.ohwr.org`, usually as a *software* subproject of the related gateware project.

6.1 Code Layout

This section is mainly for the developers who look in the code, and for me to make order in my own mind. SPEC users are expected to skip to the next section.

The `wr-nic.ko` is built using a number of headers and source files, spread over several directories:

‘`wbgen-regs/`’
: The directory hosts the register definitions for the various core that are included in the FPGA binary. The headers are generated by running *wbgen2* over the `.wb` files that are part of the VHDL source repositories; unfortunately some minor editing is needed on the *wbgen2* output, so there is a `Makefile` that takes care of this. This package includes both the input file and the output header; the log messages details the upstream origin of each `.wb` file. The directory started out as a direct copy of the directory with the same name found in `wr-switch-sw`, release 3.0.

‘`wr_nic/`’
: The directory started out as an unchanged copy of the driver used in the `wr-switch-sw` package, release 3.0. The directory name is the same in both projects. All later commits take care of differences in the SPEC with regard to the switch, but we plan to clean up those later changes and reach a unified code base between the White Rabbit switch and the White Rabbit node. The NIC driver itself is a *platform driver*, instantiated by *platform devices* defined externally.

The *wr-nic* driver refers to several headers, in addition to the register definitions. This is the role of each of them:

‘`include/linux/fmc.h`’
‘`include/linux/sdb.h`’
‘`include/linux/fmc-sdb.h`’
: These three headers are used to define the interface to the FMC bus abstraction and the SDB self-description of the internal FPGA bus. They are used by other *spec-sw* files as well. We include them as `<linux/fmc.h>` because we plan to have them upstreamed to the official kernel, and we don’t want to introduce incompatibilities in the related source files.

‘`wr_nic/nic-mem.h`’
‘`wr_nic/nic-hardware.h`’
‘`wr_nic/wr-nic.h`’
: These headers come from *wr-switch-sw/wr_nic* with minor SPEC-related modifications. *nic-mem.h* defines the memory map and is now almost obsoleted by SDB; *nic-hardware.h* is a collection of inline functions used by the driver; *wr-nic.h* defines all the important data structures and *ioctl* commands. Because of *ioctl* commands, it has a rather generic name and is meant to be included by user space as well as kernel space.

‘`spec.h`’
: Definitions related to the SPEC carrier (Gennum registers and other SPEC-internal stuff). It is currently used by *wr-nic-eth.c*, which is not completely carrier-independent.

‘`spec-nic.h`’
: The header defines the SDB vendor and device values used in *wr-nic* as well as the data structures and prototypes used internally by the driver.

‘`wr-dio.h`’
: The header hosts the user interface to access the DIO channels. It is included by *wr-nic-dio.c* as well as the user-space tools that want to configure DIO operation.

The source code of the driver itself is split in several files, in addition to the NIC platform driver hosted in ‘`wr_nic/`’:

‘`wr-nic-core.c`’
: The file is the *fmc* driver: it implements the *probe* and *remove* methods and deals with loading the firmware file and the LM32 program binary (called *wrc*: White Rabbit Core).

‘`wr-nic-eth.c`’
: This is concerned with creating the platform device for the network interface card. It maps the needed device memory, allocates the platform data and sets up the internal interrupt controller to route interrupts to the platform driver.

‘`wr-nic-dio.c`’
: This is the mezzanine-specific driver. It implements the *ioctl* commands that allow user space to talk with the mezzanine. It only implements the *ioctl* method and support functions for it (e.g., interrupt management). If you want to port *wr-nic* to a different mezzanine, this is the file you need to replace.

6.2 Overview of the Driver

The *wr-nic* driver is basically an Ethernet driver with support for hardware time stamping. The *simple-DIO* mezzanine card can be used by means of *ioctl* commands. Such commands are designed to be portable, so user-space programs should able to identify which mezzanine is connected to the SPEC network card and act accordingly.

The driver loads two binaries, using the *firmware loader* mechanism offered by the Linux kernel: one is the gateware file, that is requested through the *reprogram* carrier method; the other is the LM32 program binary, which however is only loaded on user request.

The default file names are as follows:

‘`fmc/wr_nic_dio.bin`’
: This is the *gateware* file. The default name can be changed using the `file=` module parameter.

‘`fmc/wr_nic_dio-wrc.bin`’
: This is the LM32 program file, or *White Rabbit Core*, WRC. The file is not loaded automatically, because we expect to deliver a gateware file that already includes the correct LM32 program (but the binary currently suggested does not include it). To request loading the file you should pass `wrc=1`. To request loading a different WRC file name, you should pass the actual file name. For example “`wrc=recompiled-wrc.bin`”.

The binaries suggested for this software release are available from the *files* tab of the Open Hardware Repository. The direct links are:

```
http://www.ohwr.org/attachments/download/1610/wr_nic_dio.bin-2012-09-26
http://www.ohwr.org/attachments/download/1611/wr_nic_dio-wrc.bin-2012-09-26
```

The date is included in the binary name so we won’t need to remove the binaries when they are obsoleted by newer ones: *spec-sw* releases are expected to continue working in the future, and if you are using this version you need those very files. You can copy the following command sequence to your shell in order to fill your ‘`/lib/firmware/fmc`’ with everything that’s needed to run *wr-nic*:

```
cd /tmp
wget -O wr_nic_dio.bin \
   http://www.ohwr.org/attachments/download/1610/wr_nic_dio.bin-2012-09-26
wget -O wr_nic_dio-wrc.bin \
   http://www.ohwr.org/attachments/download/1611/wr_nic_dio-wrc.bin-2012-09-26
sudo mv wr_nic_dio wr_nic_dio-wrc /lib/firmware/fmc
```

6.3 Controlling the White Rabbit Core

In this release the driver is not controlling the White Rabbit Core and the default mode of operation is *slave*. You can use the serial port and interact with the WRC shell to change the operation mode and do other supported interaction with the PTP daemon. If you want, you can use the serial port to configure a card as *free running master* storing such request in EEPROM to make it persistent.

The complete reference of the shell commands is included in the *wrpc-sw* manual in the *files* tab of the project. The direct link is http://www.ohwr.org/attachments/download/1586/wrpc-v2.0.pdf.

The most useful commands are repeated here for your convenience

`mode grandmaster`
`mode master`
`mode slave`

The commands change the current PTP mode. `mode` with no arguments reports the current mode.

`ptp stop`
`ptp start`

Stop and start the daemon running on LM32. You'll most likely need to stop and restart the PTP daemon after changing mode.

`time raw`

Prints the internal device time as seconds and nanoseconds.

`gui`

Start a self-refreshing informative display of the *White Rabbit* synchronization status. Press `<ESC>` to return to command-line mode.

`mac get`

Reports the MAC address used by WRPC (it should match what is reported by `ifconfig` in Linux.

Please note that you may also need to configure the SFP module you are using, with the `sfp` WRC command, as described in the `wrc-v2.0.pdf` manual referenced above.

6.4 Transferring Data

The *wr-nic* driver registers a Linux network interface card for each SPEC device it drives. The cards are called `wr%d` (i.e., *wr0*, *wr1*, ...).

The MAC address of the device is retrieved from the internal *White Rabbit* registers, because at the time when Linux configures the interface the WRC code has already configured the Ethernet port and generated a valid MAC address using the serial number of the internal thermometer.

The user is thus only expected to assign an Internet address to the Ethernet port to be able to use it to transfer data. Note however that *White Rabbit* synchronization happens even if the interface is not configured in Linux. In case you need to change the MAC address as seen by Linux, the command to type is something like the following:

```
ifconfig wr0 hw ether 12:34:56:78:9a:bc
```

The fiber controlled by the SPEC can carry normal data traffic in addition to the PTP frames of *White Rabbit*, that remain invisible to the host computer. The examples related to the *simple DIO* device use this data channel to exchange Ethernet frames so you'll need to assign IP addresses to your *wr* interfaces.

6.5 Timestamping Frames

The SPEC Ethernet interface supports hardware timestamping for user frames through the standard Linux mechanisms. Time stamps are currently reported with a resolution of 8ns only (*White Rabbit* does much better, but we don't have the code in place for this demo, yet).

Unfortunately the Linux mechanisms are not trivial: the application must enable timestamping on both the hardware interface and the specific socket it is using, and it must issue several *ioctl* and *setsockopt* commands. Moreover, timestamps are returned to user space using the *recvmsg* system call, which is more difficult to deal with than the normal *send* or *recv*.

To simplify use of timestamps for Ethernet frames, this package includes the '`stamp-frame`' program in the '`tools`' directory. The leading part of its source file includes generic library-like functions that deal with the intricacies of timestamping; the final part is the actual example, which is designed to be simple and readable.

The program is a minimal implementation of the basic time-synchronization protocols (like NTP and PTP), but excluding the synchronization itself. The idea is sending a frame from one host to another, and receiving a second frame back; the departure and arrival times are recorded and collected at a single place, so they can be reported to the user.

The '`stamp-frame`' example supports two modes of operations. In *listen* mode, it binds to an Ethernet interface and listens forever: it waits for the forward frames and replies to them; in normal mode it sends the forward frame and reports data as soon as it gets a reply. This is an example running on two different hosts:

```
tornado.root# stamp-frame wr0 listen
stamp-frame: Using interface wr0, with all timestamp options active

spusa.root# stamp-frame wr1
stamp-frame: Using interface wr1, with all timestamp options active
timestamp    T1:      1476.381349032
timestamp    T2:      1476.381403352
timestamp    T3:      1476.391563248
timestamp    T4:      1476.391617560
round trip time:         0.000108632
forward    time:         0.000054320
backward   time:         0.000054312
```

The four times are departure and arrival of the forward frame, followed by departure and arrival of the backward frame. Thus, time stamps T1 and T4 are collected at the original sender (here: *spusa*) while T2 and T3 are collected at the remote host (here: *tornado*). The times above are all consistent because the two SPEC cards are synchronized with *White Rabbit*. The reported forward and backward times match the fact that I used a 10km fiber to connect the two cards; the difference between them is due to the different speed of light in the two directions, because the two SFP transceivers I plugged use different wave lengths.

The following example shows the output for two forcibly-unsynchronized cards. The difference between the two clocks is clearly a few seconds; the *round trip time* is correct nonetheless, because it is a difference of differences:

```
timestamp    T1:        13.225249168
timestamp    T2:         9.130237600
timestamp    T3:         9.140438816
timestamp    T4:        13.235559016
round trip time:         0.000108632
```

```
forward    time:        -5.904988432
backward   time:         4.095120200
```

The code in '`stamp-frame`' is designed to be simple to be reused, but there is one non-obvious detail that is worth describing here. Whereas the receive timestamp is returned to user-space together with the frame it refers to, the transmit timestamp is only known after the relevant frame left the computer. For this reason, in order to communicate the TX timestamp of a frame to your peer, you'll need to send another message which carries the departure time of the previous frame. This further message is usually called *follow-up*, and '`stamp-frame`' respects this tradition.

6.6 Accessing the DIO Channels

In order to access the DIO channels, user-space programs are expected to issue device-specific *ioctl* commands. The driver supports two commands, allocated at the end of the range of command numbers reserved for device-specific use:

`PRIV_MEZZANINE_ID`
: The command is used to identify the features of the specific NIC device. It tells user space which mezzanine is currently plugged and also which type of carrier you are talking to. The command exchanges a data structure with user space in order to be able to extend its functionality over time, and such data structure includes a sub-command field. (For example, we may return EEPROM contents to user space on request).

  Warning: the command is not implemented because we still have no mezzanine identification in place. The error being returned is `EAGAIN`; user code can rely on that error to know it is actually talking with a SPEC device, even if no identification is currently possible.

`PRIV_MEZZANINE_CMD`
: The command is based on the exchange of a data structure: by means of sub-commands included in such structure user space programs can request different services to the mezzanine driver. In the case of the DIO mezzanine this includes generating pulses and timestamping input events; other mezzanine drivers will be able to use the command in a different way. The application is expected to first run `PRIV_MEZZANINE_ID` to ensure the NIC device is connected to the right mezzanine.

In the specific case of this *wr-nic* driver, the data structure is defined and explained in `wr-dio.h` and is not repeated here.

The structure includes a few integer fields and an array of `struct timespec`. Such structures define time stamps with nanosecond precision, but the *simple-DIO* mezzanine and its gateware are able to time-stamp input events and generate output events with a resolution of 8ns.

When the device is asked to timestamp input events, the array of `struct timespec` is used to return such events to user space. When the device is asked to generate output pulses at specific points in time, the array is used to pass three values: the beginning of the pulse, the duration of the pulse and (optionally) the period of the pulse train.

Specifics about the use of individual fields are shown in the header (in a big comment block), in the driver itself and in the user-space programs that call *ioctl*.

In lab environments you may be concerned about the duration of the *ioctl* implementation, because it sometimes seems to do more work than needed. To verify whether we have an over-engineering problem in kernel space, I provided a simple measurement of how much time is spent in the *Ioctl* itself. The *make* variable `WR_NIC_CFLAGS` can be used to pass extra flags to the compiler, and the macro `DIO_STAT` enables the time measurement. Compiling with the

following command thus enable such measurement and associated *printk* – the time is usually 5 microseconds for me:

```
make WR_NIC_FLAGS=-DDIO_STAT
```

Previous versions of this manual described how to command pulses on several channels with a single *ioctl* command, but that feature has never been implemented (one of the reasons is that *ioctl* revealed fast, so calling it several times is acceptable).

6.7 WR-NIC Command Tool

In the '`tools/`' subdirectory of this project, you find the '`wr-dio-cmd`' program, which is a command-line interface to the *ioctl* command that acts on the *simple-DIO* mezzanine card. Other `wr-dio-` tools are provided (and described below) but this is the most generic one.

Please note that neither timestamping nor pulse generation work if the WR core is not running or has an invalid time: it must either be a master or a synchronized slave.

Moreover, please note that this tool is just a demonstration to quickly test the I/O features of the device (and for me to verify the kernel part is actually working): for serious use you should call *ioctl* by yourself with proper arguments, and avoid all the parsing of ASCII and repeated invocation of this program.

This is the general syntax of the command:

```
wr-dio-cmd <ifname> <cmd> [<arg> ...]
```

The arguments have the following meaning

`ifname`

: The name of the network interface, most likely `wr0` (if you have more than one SPEC card, the other interfaces are called `wr1`, `wr2` and so on).

`cmd`

: The specific command. Supported commands are listed below. Each command takes zero or more of arguments. If you pass a wrong number of arguments you'll get help, and if one argument is wrong (e.g., not a number) the error message is meant to be directly helpful.

The current version of the tool supports the following commands:

`stamp [<channel>] [wait]`
`stampm [<channel-mask>]`

: The commands are used to retrieve timestamps from the card. If no arguments are passed, the tool reports to *stdout* all timestamps for all channels (they are ordered by channel, not by time). If one integer argument is passed, it can be a channel number in the range 0 to 4 (`stamp` command) or a mask in the range 0 to 0x1f (`stampm` command). If getting stamps for an individual channel, you can add the `wait` option to have the tool wait for (and report) new timestamps until killed. **Warning**: use of `wait` is dangerous because it has been implemented against the rules. You must terminate any waiting process before you unload the driver, or your PC will explode and will destroy your academic career.

`pulse <channel> <duration> <when> [<period> <count>]`

: Channel is an integer in the range 0 to 4. The duration must be specified as a fraction of a second (decimal number, less than one second), the `when` argument can be the string `now`, an absolute time (`<seconds>.<fraction>`) or a relative time (`+<seconds>.<fraction`). In the last case, the current second is added to `<seconds>` while the fraction is used unchanged. The `+` form is useful for simple checks with visual inspection. `period`, if specified, requests for a pulse train, with

the specified time period between raising edges; `count` is the number of instances to run (-1 means forever, 0 means "stop generating pulses").

`mode <channel> <mode> [<channel> <mode> ...]`
`mode <mode0><mode1><mode2><mode3><mode4>`

Configure one or more channel for the specified mode. Each mode is one character, so the second form receives a 5-byte string argument. Available modes are "`I`" (input), "`0`" and "`1`" (output, steady state), "`D`" (DIO core output) or "`-`" (unchanged). A channel managed by the DIO core is normally low and can pulse high on request (see `pulse` command. Uppercase `D` or `I` activate the 50-ohm termination resistor, while lowercase `d` or `i` disable the termination (output is always without termination, but I may add `L` and `H` if needed: the driver supports all combinations). Please note that the `pulse` command turns the affected channel in *DIO* mode anyways (without changing the termination).

Please note that generation of a pulse train is performed by software running at interrupt time, because the *simple DIO* card and gateware can only emit one pulse at a requested *White Rabbit* time. For this reason you'll have a lower limit for the pulse period, according to how powerful your computer is – and how much you loaded with other tasks. In the future, new *gateware* files may perform pulse trains in hardware.

There is no command to flush the timestamp FIFOs, but you can always "`wr-dio-cmd stamp > /dev/null`" if needed.

Example uses of the tool follow:

```
# Pulse channel 4 for 0.1 seconds now
wr-dio-cmd wr0 pulse 4 .1 now

# Pulse for 10 microseconds in the middle of the next second
wr-dio-cmd wr0 pulse 4 .00001 +1.5

# Pulse for 1ms at 17:00 today
wr-dio-cmd wr0 pulse 4 .001 $(date +%s --date 17:00)

# Get timestamps for the output events above
wr-dio-cmd wr0 stamp 4

# Make a train of 5 pulses, 0.5ms wide, every ms at next second
wr-dio-cmd wr0 stamp 4 0.0005 +1 .001 5

# Configure channel 0 as input with termination, 1 as input, 4 as low
wr-dio-cmd wr0 mode Ii--0
```

6.8 WR-NIC Pulse per Second

To better show how to write your own application with the SPEC driver and the *simple-DIO* mezzanine card, this package includes '`wr-dio-pps`', which features a very small and readable source file.

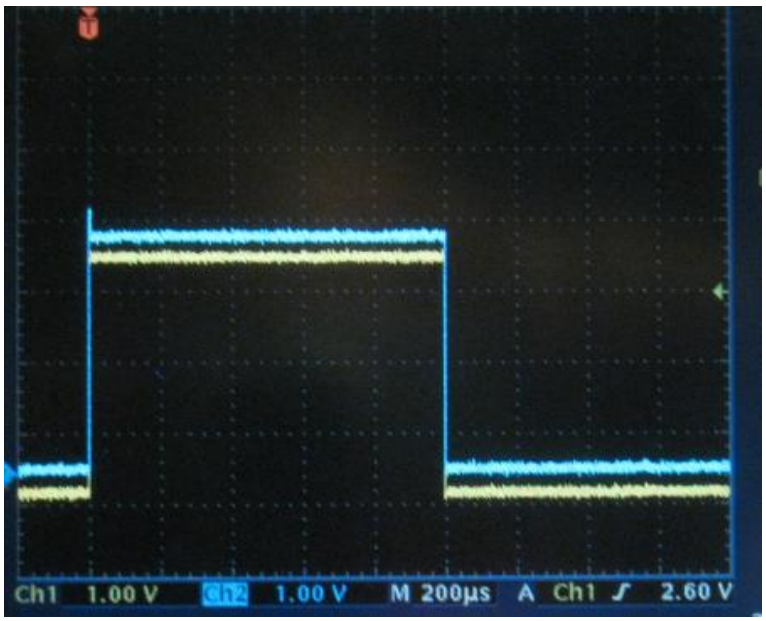
The program just fires a 1ms-long *pps* pulse on one of the output channels. The device name defaults to *wr0* but can specify a different one; the channel number is a mandatory argument.

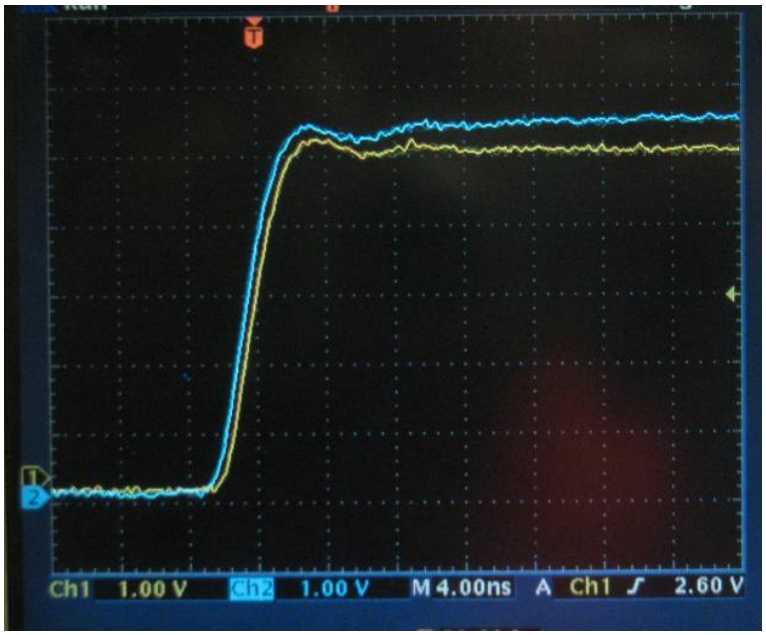
```
# run pps on channel 2 of the default SPEC card
./wr-nic-pps 2

# run pps on channel 0 of the "second" card
```

```
./wr-nic-pps wr1 0
```

The following two figures show two such *pulse-per-second* signals retrieved from two different *simple-DIO* cards, connected by a 10km roll of fiber, after syncing with *White Rabbit*. In some cases, it may happen that the leading edges differ by almost exactly 8ns; this happens because in the *simple-DIO* all times are quantized by 8ns-long clock ticks. The differences in internal delays (which depend on the carrier, the mezzanine and the FPGA binary), are not self-measured and calibrated in this simple design and may appear in the output after quantization. A more complete experimental setup would include calibration of the internal delays of the boards, like the mechanism in place for the *fine-delay* mezzanine card (see http://www.ohwr.org/projects/fmc-delay-1ns-8cha and http://www.ohwr.org/projects/fine-delay-sw).





6.9 Distributing Output Pulses

A typical application for *White Rabbit* (or any time synchronization system) is being able to generate output signals at the same time in different output boards; another typical application is time stamping input events.

By using the Ethernet interface included in the SPEC, an application can exchange data with other *White Rabbit* devices; thus, it can easily request output event to other output peripherals, or collect remote input events. The tool-set offered by the driver is made up of the the `PRIV_MEZZANINE_CMD` *ioctl* command, amd the usual Posix API for network communication.

The *DIO-specific ioctl* command is the one used by the `wr-dio-cmd` tool described above, while network communication should be known to most users of this package. In order to ease new *White Rabbit* users, though, this package includes sample code to implement a simple dual-headed system with concurrent output. The examples are also meant to show the basic code that uses the provided *ioctl* command, without all the boring parameter parsing that is required in more generic tools like `wr-dio-cmd`. Because of this simplification of parameter passing, the pulse width is hardwired to 1ms.

The example is made up of two programs: `wr-dio-agent` and `wr-dio-ruler` (the former is a dumb actor, while the latter states the rules). To keep things simple the two programs assume that the SPEC is connected point-to-point to another SPEC and both carry the *simple-DIO* mezzanine.

Under this simplified assumptions, the *ruler* transmits raw Ethernet frames to the broadcast address, while the *agent* receives almost everything that appears on the cable. This choice allows plugging two SPEC cards in the same computer and run the example; if the example used an IP-based protocol (like UDP) it couldn't be used with two cards on a single PC – and a fiber through them. The simplification above, however, most likely prevents the programs from working within a more complex network topology. I expect real *White Rabbit* users to add proper network addressing in their applications.

If you have a single SPEC card, you can still use the *ruler* by itself to mirror an input channel to an output channel of the same card, with a specified delay.

The *agent* program silently listens to the network interface and receives a data structure ready to be passed to *ioctl*. Its only command line argument is the name of the *White Rabbit* interface to use (for most users it is `wr0`):

```
wr-dio-agent wr0
```

The *ruler* command, on the other hand, waits for timestamps to appear on the specified input channel; when notified about a positive-going edge, ot replicates the edge on one or more outputs. Each output can be local or remote, and can use a different delay from the input pulse.

If you lack an input signal, you can make an output pulse with `wr-dio-pps` or other means and use it as a trigger. Please note that the *ruler* does not configure the channel mode, so you might want to use the `mode` command of `wr-dio-cmd` in advance.

The following command waits for events on channel 0 of the card connected to *wr1*, and replicates the event with a delay of 1ms on channel 3 of both the local and the remote card; it also replicates with a 2ms delay to local channel 4. Please note that the delays should be no more than the interval between input pulses, because the tools reprograms all output triggers at each input event.

```
wr-dio-ruler wr1 IN0 L3+0.001 R3+0.001 L4+0.002
```

There is no sample code that generates trains of pulses as a response to events, nor support for other than 1ms-long output pulses; anyways, the code is thoroughly commented in order to serve as a starting point for more complex lab environments.

As a final remark, please note that all pulse generation is driven by host software, after an hardware interrupt reports the input event. For this reason, you'll not be able to reliably replicate pulses with delays smaller than a few hundred microseconds, depending on the processing power of your computer and the load introduced by other processes. For remote connections, you must also count the overhead of network communication as well as transmission delays over the fiber (a 10km fiber introduces a delay of 50 microseconds).

The following example shows use of the *ruler* and *agent* on two hosts, called `spusa` and `tornado`. The input events on `spusa` are replicated to one local channel and two remote channels, with a delay of 1ms. The input events in this case are from a *pulse-per-second* signal:

```
tornado.root# /tmp/wr-dio-agent wr0 &

spusa.root# wr-dio-ruler wr1 IN4 L3+.001 R4+.001 R2+.001
wr-dio-ruler: configured for  local channel 3, delay 0.001000000
wr-dio-ruler: configured for remote channel 4, delay 0.001000000
wr-dio-ruler: configured for remote channel 2, delay 0.001000000

[... wait a few seconds ...]

spusa.root# wr-dio-cmd wr1 stamp 3
ch 3,       385.001000000
ch 3,       386.001000000
ch 3,       387.001000000
ch 3,       388.001000000
tornado.root# wr-dio-cmd wr0 stamp 2
ch 2,       385.001000000
ch 2,       386.001000000
ch 2,       387.001000000
ch 2,       388.001000000
tornado.root# wr-dio-cmd wr0 stamp 4
ch 4,       385.001000000
ch 4,       386.001000000
ch 4,       387.001000000
ch 4,       388.001000000
```

6.10 The Future of WR-NIC

The *grand plan* for this driver is to detach the NIC functionality from the mezzanine driver.

Some future version of this package will thus feature a different layout of the code, and the NIC will be a mezzanine-independent feature that may be activated on request of the mezzanine driver – it's the mezzanine driver that requests its own gateware to be loaded, and only that driver can know whether or not NIC functionality is part of its feature set.

In any case, no change to user-space access is expected, because the current way to handle mezzanine-specific *ioctl* commands is already portable to the new code arrangement.

7 User-Space Tools

The *tools* subdirectory of this package includes a few host-side programs that may be useful while working with the SPEC device. This section does not describe the *wr-nic* specific tool; for that see Section 6.7 [WR-NIC Command Tool], page 10.

They are all base on the same *speclib*, part of the same directory, so all of them accept some parameters in common, in order to identify one specific SPEC card if you have more than one:

`-b <bus>`

This option specifies the bus number

`-d <devfn>`

This is used to specify the device and function number, but it is expected to be 0 on most if not all the computers. You won't generally need to specify the *devfn* value.

If no arguments are supplied, the tools act on the *first* device if more than one is plugged. The meaning of *first* is actually undefined and system-dependent.

The tools currently available are:

specmem

The program acts like *devmem* or *devmem2* but in a simplified way. It receives one or two command line arguments: one for reading and two for writing. Both arguments are used as hex numbers, whether or not the leading `0x` is specified. The program makes a single 32-bit access to BAR0 of the Gennum PCI bridge; the first argument is the address, and the second argument is the value to be written. The `VERBOSE` environment variable makes the tool slightly more verbose. If you pass `-g` you will access the Gennum registers (for example, for GPIO access).

spec-cl

This is the *cpu loader*. It is not called *lm32-loader* to avoid confusion with other tools we have been using. It loads a program at offset 0x80000 in BAR0. This is where we usually have RAM memory for the soft-core running in the SPEC. If the program lives at aa different address, you can pass `-c <number>` to specify a different address (note that the leading `0x` is required to pass an hex address).

spec-fwloader

This is a user-space loader for the gateware file. It simply receives a file name argument (after the optional bus number for the device).

spec-vuart

A simple tool to talk with the virtual-uart device inside the SPEC. The default base address for the peripheral is 0xe0500 but you can can change it passing `-u <address>`.

8 Bugs and Missing Features

- Identification of the mezzanine is completely missing; every *fmc* driver at this point takes hold of every device. We are working on this, and the next version of spec-sw will support identification, with a flag to run without identification for users whose EEPROM has not been programmed.
- Both spec and wr-nic should have GPIO support with *gpiolib*; there is skeletal support but no real code for actual I/O. This is not a priority, just a wish list for better Linux integration.
- The NIC driver should directly support setting the White Rabbit mode for each card (grand-master, free-running master or slave). This will be supported at module load time, not at runtime (for that please use the UART).
- DIO support in *wr-nic* is missing some of the features listed in '`wr-dio.h`' (i.e. DAC control)>
- The *wr-nic* functionality should be completely detached from the specific mezzanine. This is a longer-term desire.
- Locking in kernel code should be verified with a serious audit effort. There are no known issues at this point, but some code may be made safer.