Summer Student Work Report

DEVELOPMENT OF HARDWARE CONFIGURATION AND TESTING TOOLS FOR THE FELIX PROJECT

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Abstract
This document contains a report about the work I have been doing during my stay as a summer student at CERN. The work described here is part of the FELIX project, a new system that will be progressively integrated in the ATLAS Data Acquisition System during Long Shutdowns 2 and 3. Specifically, my task consisted of the development of testing and configuration software for FELIX.

1 Introduction

The Data Acquisition (DAQ) System is a fundamental part of the ATLAS experiment. It filters the 40 MHz collision rate generated by LHC, reducing it by a factor of O(10000), and stores the information for offline analysis. Due to the high rate of events (100 kHz after the L1 trigger, 1-2 MB of data per event), the DAQ system has to decide in quasi real time if an event is accepted or rejected.

As part of the upgrade to raise the DAQ throughput, increase fault tolerance and ease maintenance, most components which nowadays are used as intermediaries between the front-end detectors and the central data-acquisition system (where events are constructed) will be replaced. The introduction of a switched network will allow easy flow management with dynamic routing rules, monitoring, and load balancing [1]. At present, each detector has its own dedicated custom point-to-point link, which complicates maintenance and monitoring. A new substitute system, FELIX, the Frontend Link Exchange, will provide a common interface to connect the output and input of all detectors to a commercial-off-the-shelf (COTS) network. FELIX forwards event data to the DAQ system and, in the opposite direction, control and calibration information to the detectors.

With this new system, DAQ performance will be enhanced, keeping up with the LHC and ATLAS improvements after Long Shutdown 2 and 3.

1.1 FELIX system

FELIX [2] is a PC-based multi-interface device designed to mediate between ATLAS detectors, which use the GBT protocol [3], and the ATLAS DAQ system. It is composed of a computer with a PCIe card called FLX consisting of an FPGA and electrical or optical connectors to interface the GBT links. The GBT protocol is implemented on the FPGA. Routing and forwarding of data to and from the ATLAS DAQ system is done in software by the FELIX PC.

The firmware for these FLX cards is being developed and is planned to be ready by 2018, when FELIX is going to be deployed for a subset of the ATLAS detectors. Right now, the FELIX developer team works with different FELIX prototypes to test different candidates of FPGA card models.

In order to ease these studies and to operate and monitor the cards, a set of programs running on the FELIX prototype were required. These programs are called Flxtools.

2 Flxtools

As the name suggests, Flxtools is a collection of tools designed to be used as control and configuration tools for the FLX card. These tools provide an easy way to configure, test and monitor different aspects of the FELIX GBT interface, allowing developers to save time and effort while improving the quality of testing.

Some tools existed before and have been expanded. Other tools are new and have been developed from scratch. The Flxtools have been programmed using the C language. At present they can operate with two models of the FLX (FLX-710 and FLX-709, based on the boards HTG-710 and VC-709, see Ref. [4] and Ref. [5]), with the possibility of extending support to other cards. Their interface is designed to be user friendly and easy to remember, without the necessity to consult the documentation whenever the tools are used (Example 1).

Example 1: Listing of Flx-info options.

```
Usage: flx-info [OPTIONS] COMMAND [CMD ARGUMENTS]
Displays information about a FLX device.

Options:
   -d NUMBER                        Use card indicated by NUMBER. Default: 0.
   -v                               Verbose mode.
   -h                               Display help.
Commands:
   GBT                              Shows GBT channel alignment status.
   FMC_TEMP_SENSOR                  Display FMC temperature from TC74 sensor.
   FMC ADN                          Display FMC ADN register 0x4.
   CXP                              Display temperature and voltage from CXP1 and CXP2
   SFP                              Display information from Small Form Factor Pluggable
                                           transceivers
   CDCE                             Display some values from CDCE clock
   DDR3                             Display values from DDR3 RAM memory
   EGROUP       [channel]  [RAW]    Display values from EGROUP registers:
                                       If no channel is specified, display all available.
                                       Using Hexadecimal notation if RAW is specified.
   ALL                              Display ALL information.
```

Flxtools are installed on FELIX PCs and can access the FLX registers via a small dedicated kernel driver. The programs that compose Flxtools are divided by functionalities, focusing on different parts of FELIX. There are 5 tools in total, and all of them accept a set of common options (Table 1).

The general call for all tools is:

flx-tool [command] [command-option] [general-options]

with the name of the program (e.g.,: config, info, i2c, ...) instead of ¨tool¨. Specific information (and functionalities) of each tool can be found inside the following subsections.

Table 1: General options

Option	Description
-v	Verbose output which let developers know more details about the execution of the program.
-h	Displays a message on the terminal with all different commands and parameters that can be used, as well as a short description on each one of them.
-d [NUMBER]	Some developers work with multiple cards. This option lets them decide which one will be the target of the execution. Different cards implies in most cases different hardware and devices. Therefore all tools have to be capable of working with any of them.

2.1 Flx-config

Flx-config is used for reading and writing raw data from the FLX cards. It is able to display all registers with their address and current value. When a user tries to access to a register, Flx-config uses the name assigned to the register as index for a lookup table to find the register's address. Users do not need to know the bare addresses, and can instead rely on more convenient name aliases.

The actual addresses are hidden and easy to change, transparent for the user. Additionally the tool allows saving and loading the full register map to/from a file, making it possible to have a backup of a configuration.

2.2 Flx-reset

Flx-reset allows developers to restore the initial internal state of the FPGA. It provides options to reset only parts of the firmware state and to flush internal buffers.

2.3 Flx-i2c

FLX cards usually have many on-board chips that can be accessed via the I²C protocol [6]. Depending on the PCIe model, chip addresses and I²C switch port may vary. In a similar way to Flx-config, Flx-i2c maintains a list of available I²C devices and their addresses per card model (Table 2).

Table 2: Currently available devices for the two supported card models

```
Card model FLX 710
Switch I2C address: 0x70

List of available devices:
Device              Model                   Switch port       Address
========================================================================
CLOCK_RAM           ICS8N4Q001L IDT             0:0             0x6e
CLOCK_SYS           ICS8N4Q001L IDT             1:0             0x6e
CLOCK_CXP1          IDT 8N3Q001                 2:0             0x6e
CLOCK_CXP2          IDT 8N3Q001                 3:0             0x6e
FMC_ADN             ADN2814 (on TTCfx FMC)      4:0             0x40
FMC_TEMP_SENSOR     TC74 (on CRORC TEST FMC)    4:0             0x4a
CXP1_TX             AFBR-83PDZ                  5:0             0x50
CXP1_RX             AFBR-83PDZ                  5:0             0x54
CXP2_TX             AFBR-83PDZ                  6:0             0x50
CXP2_RX             AFBR-83PDZ                  6:0             0x54
DDR3-1              SRAM-MT16JTF25664HZ         7:0             0x50
DDR3-2              SRAM-MT16JTF25664HZ         7:0             0x51
```

```
Card model FLX 709
Switch 1 I2C address: 0x74
Switch 2 I2C address: 0x75

List of available devices:
Device              Model                    Switch port       Address
=========================================================================
USR_CLK             SI570                        0:0             0x5d
FMC_ADN             ADN2814                      1:0             0x40
FMC_TEMP_SENSOR     TC74 (on CRORC TEST FMC)     1:0             0x4a
ID_EEPROM           M24C08-WDW6TP                3:0             0x54
SFP1-1              AFBR-709SMZ (Conven Mem)     4:0             0x50
SFP1-2              AFBR-709SMZ (Enhan Mem)      4:0             0x51
SFP2-1              AFBR-709SMZ (Conven Mem)     4:1             0x50
SFP2-2              AFBR-709SMZ (Enhan Mem)      4:1             0x51
SFP3-1              AFBR-709SMZ (Conven Mem)     4:2             0x50
SFP3-2              AFBR-709SMZ (Enhan Mem)      4:2             0x51
SFP4-1              AFBR-709SMZ (Conven Mem)     4:3             0x50
SFP4-2              AFBR-709SMZ (Enhan Mem)      4:3             0x51
DDR3-1              SRAM-MT8KTF51264HZ           6:0             0x51
DDR3-2              SRAM-MT8KTF51264HZ           6:0             0x52
REC_CLOCK           SI5324                       7:0             0x68
```

This tool provides an easy transparent way to connect to the different I²C devices on the FLX. Its functionality is also used by others tools (like Flx-info) via an API to retrieve status information. A simple command line interface can be used by users to write or read from known devices. Additionally the tool supports a more complex syntax which allows to access to devices which are not specified in the database.

2.4 Flx-spi

Flx-spi has the same functionalities as Flx-i2c for SPI [7] devices. Currently only a clock recovery chip can be accessed by this tool.

2.5 Flx-info

Flx-info prints decoded information of raw data retrieved from FLX registers using the Flx-config API. It also recovers and decodes information about different I²C devices connected to the card using the Flx-i2c API.

The main functionality of this tool is to provide users with a fast and easy way to know the status of the different devices without having to interpret encoded hexadecimal values. This program can be considered as a high level tool as it uses other tools to acquire and show the info.

By default the tool displays general information about the card status. More detailed information about specific devices can be requested by the user using command line arguments.

2.6 Flx-init

Flx-init was created to load the initial configuration of an FLX. This includes starting the internal clock, training and calibrating the GBT channels as well as adjusting their phases with the external clock.

A large number of command line options allow configuring many different scenarios. Thus users and developers can use this tool to test different FPGA firmware configurations and features.

3 Contributions

During my stay as a Summer Student at CERN, my work consisted in improving Flxtools, either by extending the existing tools with new functionalities (Flx-config, Flx-info and Flx-init) or developing new ones.

Specifically, Flx-spi and Flx-i2c have been created to provide a common interface for users and other tools to access peripheral devices. New functionality has been added to the Flx-info tool, based on Flx-config, Flx-i2c and Flx-spi. It now accepts different options to display information related to a specific device. Flx-reset is another new tool allowing programmers to reset different parts of the FLX firmware.

Additionally, Flx-init can now train the FLX card's transceivers and clock recovery modules. For this the internal register map was expanded. Flx-init takes a variety of command line arguments to adjust the calibration process. In general, the command line interfaces of all tools have been unified and the tools' output has been improved to be more clear to users. Furthermore, the Flxtools have been ported to the VC-709 card (HTG-710 was already supported). The internals of the implementation were designed to easily add support for new cards in the future.

4 Conclusion

Testing of FLX PCIe cards was done using low level programs with disparate syntaxes difficult to use and harder to remember. Also, these programs were not really useful only being capable of reading and writing on specific registers or using a fixed configuration.

Flxtools is designed to solve this problem. It provides a high variety of tools with a friendly, homogeneous interface and very powerful functionalities. These let programmers and users test and operate FELIX systems, increase their productivity and effectiveness.

References

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[6] NXP, I²C-Bus specification and user manual, Rev 6, (4 Apr 2014).

[7] Motorola Inc, SPI Block Guide, (4 Feb 2003).