EMBEDDED CONTROL SYSTEM FOR PROGRAMMABLE MULTI-PURPOSE INSTRUMENTS

Acknowledgements:
Agenda

- Project Concept
- Electronic design
- Software Project
- Conclusions
Project Concept

Electronic design

Software Project

Conclusions
ALBA is a 3rd generation Synchrotron Light facility located in Cerdanyola del Vallès, (Barcelona), being the newest source in the Mediterranean area.

ALBA has a 3 GeV electron beam energy. It currently has eight operational beamlines, comprising soft and hard X-rays, which are devoted mainly to biosciences, condensed matter. There are two beamlines in construction (low-energy ultra-high-resolution angular photoemission for complex materials and microfocus for macromolecular crystallography).
Product concept

- ALBA developed years ago a 4 independent channel electrometer
  - To measure from various sources of different nature and magnitude synchronously, while remaining flexible at the same time

- Overall performance is very good but minor changes are needed

- Em# arises to solve that few limitations and provide new functionalities to make it more versatile and customizable.
  - Use of standard interfaces to interconnect devices
  - Increase performance of ADC
  - Use an open-hardware (OHWR) FPGA board
    - Big community of OHWR developers, where to collaborate
  - Control application in a Single board computer (SBC)

- Open collaboration between institutes: ALBA, MAX-IV,…
Project Concept

Electronic design

Software Project

Conclusions
The hardware of the equipment is composed by the following boards:

- Simple PCI Express FMC Carrier (SPEC) (commercial, OHL)
- FPGA Mezzanine Card (FMC) (developed, OHL)
- Single Board Computer (SBC): Intel NUC DE3815TYBE (commercial)
- Front-End Board (FE) (developed)
- 4x ALBA Current amplifier (CAX) (modified)
- Current Amplifier Carrier Board (CACB) (developed)
- Power Supply Board (PSB) (developed)
- Display (commercial)
Project Concept

Electronic design

Software Project

Conclusions
Software Design

Involves to three software projects all together distributed in a single package

- The Operating System:
  - LINUX: It's Customizable, Open Source, Free, Fast, Secure, Well-Supported...

- The gateware (FPGA software)
  - High performance and fast data acquisition

- The main control software in the SBC (ALIN)
  - Manage different operations to control the Em# reducing the FPGA SW load & complexity
  - Standard, easy to develop, flexible and have a big performance
1. Linux OS

Which LINUX distribution?

**Pre-built Binary Linux Distributions (Debian, SUSE,..)**

+ Readily available
- Large, usually 100+MB
- Not available for all architectures
- Not easy to customize
- Generally require native compilation

**Embedded Linux Build systems**

+ Small and flexible
+ Reproducible, handles cross-compilation and dependencies
+ Available for virtually all architectures
- One tool to learn
- Build time

Wide range of solutions: Yocto, PTXdist, Buildroot, LTIB, OpenBricks, OpenWRT...

**Manual System building**

+ Smaller and flexible
- Very hard to handle cross-compilation and dependencies
- Not reproducible
- No benefit from other people's work

**YOCTO**

- Builds a complete Linux distribution with binary packages.
- Powerful, and although it is complex and quite steep learning curve, it is quite flexible and offers a high rate of configurability
- Easy to combine it with a SVN, GIT, ...

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2. Gateware

High performance and fast data acquisition

- Main software in SBC is not fast enough to get and process the acquisition data at 400KSamples/Second for the 4 channels via PCI.
- Acquisition through the fast acquisition bus: Harmony.


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1. **Slow bus:**
   - Direct read of the FPGA blocks
   - Use of the SDB structure
   - Register map in external files auto-generated

2. **Fast bus (Harmony):**
   - Use of dynamic ID’s.
   - The SBC configures the ID’s using the slow bus
   - FPGA stores data in the memory using the Fast Bus with ID and timestamp.
Main considerations:

- Possibility to add new functionality /requirements easily.
- Use of the Self Describing Bus (SDB) structure to access the FPGA data.
- Easy integration in any control system: ASCII commands following the Standard Commands for Programmable Instruments (SCPI).
- Local control through a touch-screen display
3. Main control software – ALIN (2/7)

Self Describing Bus (SDB)

- Developed by CERN OHR group. [http://www.ohwr.org/](http://www.ohwr.org/)
- Allows to enumerate the cores that are available in the current FPGA binary
- It is a self description structure that provides metadata about the logic blocks.
- Each block is assigned to a virtual memory address and its contents is defined in the FPGA code (configuration parameters or data).
3. Main control software – ALIN (3/7)

Software architecture in SBC

- Simple applications to control the EM.
  - Locally via the Display or the Touch panel
  - Remotely via list of functions through remote telnet console (ASCII)

- Communication protocols or main EM Functions, Diagnostics, Display control, Webserver, Touch control, Others...

- Software code of drivers that control physical devices like SPEC, FMC, TCP/IP, Serial, Display, FPGA, SCPI...

Hardware:
- USB/Serial
- I2C
- PCIe
- TCP/IP

Drivers

Middleware

Applications

Users
Software architecture in detail

- **Harmony Ctrl (R/W fns(Fast/Slow Bus))**
  - ADC CORE
  - FIFO
  - ID Gen
  - AVG
  - MEM
  - SPI
- **ALindev**
- **Em# Main App**
- **Web Server**
- **SCPI Cmd**
- **Diags**
- **Display**
- **Spec.ko**
- **Fmc.ko**
- **tcp/ip**
- **i2c_dev.ko**

Drivers:
- PCIe
- SPEC (FPGA)

Middleware:
- Linux Drivers

Apps:
- Linux (Yocto)
- Middle ware
- Apps

Network:
3. Main control software – ALIN (5/7)

- **Main equipment control**
  - In the middleware **Harmony Control** module.
    - Configures the acquisition
    - Starts/stop it
    - Process the acquired data in the FPGA memory.
    - Use of an external configuration file with predefined parameters.
  - Specific FPGA block drivers contain commands like init, start, read data,..

- **Alindev.py** individual control of FPGA blocks
  - Access to configuration parameters
  - Data access through virtual memory address.
  - Device pickle files containing the register map (SDB structure)

- **Alin.py** gets the SDB structure.
  - Available blocks in the FPGA
  - Virtual memory addresses for each block.

- **Spec.ko** and **Fmc.ko** linux kernel drivers (source code provided by OHR) provide FPGA access
3. Main control software – ALIN (6/7)

- Remote monitoring & control
  - Via Communications ports 5025:
    - ASCII commands that follow the Standard Protocol for Programmable Instruments (SCPI).
    - List of commands and their corresponding call-back in SCPI middleware while protocol in SCPI driver.
  - SSH:
    - Expert control for designers
    - Handful set of tools to check/configure the FPGA

- Via Web (port 8888)
  - Webserver middleware starts/stops the server and generates data JSON file periodically.
  - Web contents updated in browser client using JavaScript and jQuery to read the JSON file.
  - POST PHP method is used to execute equipment commands in server side.
3. Main control software – ALIN (7/7)

- **Diagnostics**
  - Check the harmony bus stability
  - Check FPGA cores failures
  - PSB board control and consumption self-detection using **Ads7828** (ADC) and **Mcp23008** (Port-Expander) drivers via I2C.

- **Local control**
  - Through the touch-screen display.
  - Navigation menus allowing user control in the **Display middleware**.
  - High-level language communication protocol via I2C in the **edip128 driver**.
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Conclusions

- Em# achieves unique characteristics in an electrometer (accuracy, bias voltage, processing capabilities…) with a reduced cost
- The software project is modular and easy to adapt to any other similar hardware approach.
- Easy integration into any control system.
- Clear separation between FPGA and SBC responsibilities
  - Configuration and control resides in the SBC
  - Data acquisition in the FPGA.
- Functionality not limited to work only as an electrometer
  - It can be easily adapted and extended
Questions / Comments?

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See you soon....