Control instrumentation and X-ray detectors for synchrotron radiation facilities

Pablo Fajardo  (fajardo@esrf.fr)
Detector & Electronics Group - ESRF

ESRF  The European Synchrotron
22 PARTNER COUNTRIES

13 Member states:
- France 27.5%
- Germany 24.0%
- Italy 13.2%
- United Kingdom 10.5%
- Russia 6.0%
- Benesync 5.8%
  (Belgium, The Netherlands)
- Nordsync 5.0%
  (Denmark, Finland, Norway, Sweden)
- Spain 4.0%
- Switzerland 4.0%

8 Associate countries:
- Israel 1.5%
- Austria 1.3%
- Centralsync 1.05%
  (Czech Republic, Hungary, Slovakia)
- Poland 1.0%
- Portugal 1.0%
- India 0.66%
- South Africa 0.3%

ESRF is an international collaboration founded on an intergovernmental convention (1988)

Annual budget: 100 million euros
Staff: 630 of 40 different nationalities
Legal status: Private civil company subject to French law
1988 – 2018

World Leader in Enabling Science

- 22 partner countries
- 10,000 scientific visits per year
- 44 beamlines
- 4 Nobel Prizes
- 2,000 publications per year
- 330 M€ over 2009-2022
  - 2009-2022: delivery of a new portfolio of beamlines
DELIVERABLES OF THE ESRF-EBS PROJECT

EBS
2015 - 2022

Ultra low Emittance Storage Ring

New X-ray Detectors and instrumentation

4 new Beamlines & 6 major refurbishments

Data Analysis and IT

New, better science

Structural/functional biology and soft matter

Science at extreme conditions

Pumps and pipeless cooling and integrated detection

Nanoscience and nanotechnology

ILO Industrial Opportunities Days – June 2019 – P. Fajardo
- Increase of Ethernet connected devices / Field buses replaced by Ethernet
- Linux based – very few Windows systems (for “standard” equipment)
- Obsolescence management is a permanent issue
- Software / Control systems: **TANGO** for accelerator complex, **BLISS** for experiment control
MOTION CONTROL – SOME EXAMPLES

4 Accelerator GIRDERS per storage ring cell (129 total)
Magnet supports, Magnets, Vacuum equipment, Diagnostics
Fully equipped girder: ~12-13t

4 adjustable feet with motorised wedges
Total: 512 axes + 512 sensors

Raman spectrometer – ID20
~250 motorized axes

ID32 RIXS Station – ID32
6 tons, 11m long scattering arm
micrometer resolution
In-house development

- Interface of choice for the ESRF control system
- High performance stepper motor control
- Cost effective solution

Also used for other types of motors with adequate interfaces

- About 7000 axes at the ESRF
- Collaboration with ALBA & MAX IV
- Close to 10000 in total

- 8 axes per crate
- 1 controller board
- System up to 128 axes

- Call for tender – Technical & Economic criteria
- Multi-annual contracts (typically 3 years)
  ~ 200 crates per CFT
- Next ESRF CFT potentially in 2021
• For applications where ICEPAP does not do the job (e.g. power > 300W)
  ✓ **COTS controllers** - interfaced or not with IcePAP
  ✓ Specified or/and chosen or/and validated by ESRF
  ✓ Directly bought by ESRF or, more frequently, procured by the subcontractors in charge of instrument/mechanics design and production
  ✓ Quantities over 5 years: #20 units

• For very demanding and specific applications such as fast chopper control:
  ✓ Specified / validated by the ESRF)
  ✓ Provided with the mechanics by the subcontractors in charge of the instrument
  ✓ Quantities over 5 years: few units

*High-speed chopper*[ up to 100 krpm ]
NANO-POSITIONING

- Nanopositioners: devices capable of positioning objects in the nanometer range
- Technologies: most commonly, piezo actuators/motors (specific controllers)
- Sensors and metrology: capacitive sensors, interferometers
- Procurement:
  - Off-the-shelf turn-key solutions (hexapods, translation stages)
  - Actuators and sensors to be integrated by the ESRF
  - Quantities over 5 years: few dozens
BL CONTROL – IN-HOUSE DEVELOPED ELECTRONICS

. Stand-alone
. Ethernet control

. Highly Standardized:
  Hardware, Firmware, Software

. Reduce development lead time

DAnCE

Data Acquisition & Control Electronics platform

ESRF “standard” hardware modules

. Standard Digital board (FPGA + ARM)
. Standard or customized carrier board
. Embedded in 19”case

. A range of instruments for Beamline control
  ➔ Counting, sequencing, encoder processing, ...
  ➔ supports FMC mezzanines

. And also Accelerator specific applications

Qseven  ARM® processor SBC

FPGA and tool chain.

CAD

ILO Industrial Opportunities Days – June 2019 – P. Fajardo
ELECTRONIC INSTRUMENTATION: SERVICES & PROCUREMENT

. Design Phase:
   ➔ Subcontracting Design/Schematic of electronic boards based on ESRF specifications
   ➔ Place & Route
   . Expertise in digital - High demanding applications
   . Know-how & tools: FPGA Xilinx, Altium CAD
   . Mechanical design
   . Project management

. Prototyping:
   ➔ PCB + components - embedded or not in mechanical frame
   ➔ Cabling, integration, …
   . Good reactivity, low cycle time
   . Process & supply-chain adapted to prototyping
   . Know-how, advice

. Production:
   ➔ Procurement process depends on quantities/total estimated price: Call for Tender or Request for quote
   . Capability & Quality & Prices
   . Testing capabilities
   . Respect of lead times

. In the coming 5 years:
   ➔ PCB design outsourcing: > 5 per year
   ➔ Few hundred units embedding our “standard” digital board
   ➔ 50% with standard carrier  I  50% with specific carrier
   ➔ # 100 FMC-like electronic boards
OTHER INTERFACE MODULES – DEVELOPED IN-HOUSE

Voltage to frequency converters 100 MHz

Regularly procured by medium quantities (20 to 50 units) depending on the needs

Positioning Encoder Processing Unit

IcePAP - Encoder interface
Sin-Cos, EnDAT, Bissc
**ACCELERATOR TIMING & SYNCHRONISATION SYSTEM**

. Open HardWare modules:
  . SPEC boards
  . WR Switches
  . Firmware Features

. WHIST: A module developed by the ESRF
  . Entered in operation in the 2nd half of 2018
  . Already a dozen of modules manufactured

---

**White Rabbit based network**

[ CERN technology ]

Carrier board (ESRF) + SPEC board embedded in a 19” case

. In the coming 5 years:
  - around 20 switches
  - > 50 WHIST modules

Complete White Rabbit network built on WR switches
MECHATRONICS – REAL TIME CONTROL

- Enhance the performance of new experimental stations:
  
  Stability, Accuracy, Speed

- Fast feedback loop \([x \text{ kHz}]\)
- Deterministic

- Developments already on-going based on a COTS solution for the RT unit
- Some \# 20 systems foreseen in the coming 5 years

![Diagram](image-url)
X-RAY DETECTORS AT THE ESRF

A diversity of off-the-shelf and customised instruments

**Selection based on:**
- Technical characteristics / performance
- Cost

**Constraints**
- Software integration
- Support / maintenance
- Quick diagnostic
- Availability of components

Estimated expenditure in detectors at ESRF

2019-2023: 10 to 15 M€

Usually via CFT (Call-for-Tender)
Usually always custom detectors based on standard cameras + customised optics
Price depends on the choice of the camera and complexity of the optical design
Variable price from 30 k€ to 200 k€
Main technologies

- **CCD based**
  Indirect (hard X-rays) or direct (soft X-rays) detection schemes
  Mature technology (little room for improvement)

- **Flat panels** (medical imaging)
  - a:Si (TFT technology)
  - CMOS flat panels (tiling or CMOS image sensors)

- **Hybrid pixel detectors**
  - Photon counting operation
  - Modular devices
Examples of detector systems in operation (not only at ESRF)

- **Photon counting**
  - Few megapixel devices
  - Now standard devices at synchrotrons

- **Charge integrating**
  - Designed for X-ray free-electron lasers
  - Can cope with very intense pulses

**Typical price of “catalog” pixel detectors:**
- From 100 k€ (small module)
- To 2 M€ (large format)
Off-the-shelf detectors (most used in practice in SR experiments):
- Silicon drift diodes (SDDs)
- High purity germanium detectors (HPGe)

Customised instruments (multielement and special devices):

ESRF/ID16A
- SDD 6 element arrays = 2 x 540mm²
- Energy range ~2...20keV

Price range: from 20 k€ (simple single element module) to 300 k€ (multielement based on standard components)
• Partners for technology development
  • X-ray sensor developments, specially high-Z material
  • Optics for indirect detection

• Licenses

• Production
  • Hybrid pixel detector (Maxipix)
  • CCD camera (Frelon)
  • Scintillator (GGG:Eu, LSO:Tb)
  • X-ray beam viewers
THANK YOU FOR YOUR ATTENTION