Low Level RF for SRF accelerators.

... based on the European XFEL experience

1. Interfaces to LLRF?
2. LLRF for large scale accelerators

Julien Branlard, DESY
for the LLRF team

LLRF for SRF accelerators
Geneva, September 3rd 2014
WHY TALK ABOUT LLRF?

> “Everything already demonstrated since analog LLRF systems.”

BUT

> “New technologies open new possibilities, offer new challenges.”
WHAT IS LLRF?

> Interface to « The Ultimate LLRF System »

![ACCELERATOR LLRF Interface](image-url)
WHERE DOES LLRF STOP?

LLRF

Couplers
High power RF
End Experiment
Operation
Machine protection
Controls
Diagnostics
Beam
Cryogenics
Personnel interlock
Cavities
PART I

> INTERFACES TO LLRF

> LLRF FOR LARGE SCALE ACCELERATORS
LLRF and Cryogenics

- **Quench** detection
- **Heat load** anticipation / compensation
- Cryo OK → tuners, piezo

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**Online QL calculation**

* Courtesy: R. Rybaniec

"Real-time Estimation of Superconducting Cavities Parameters"
IPAC 2014, Dresden Germany
> Power **sub-distribution** and **phase shifters** control

![Diagram of power sub-distribution and phase shifters control](image-url)
**Klystron monitoring**

1. RF break-down
2. "Too-high" reflected power
3. High voltage break-down

- Fast interlock of the LRF drive
- 200 nsec reaction time
LLRF and Operation (1/2)

- RF station ON/OFF
- Finite State Machine
- Exception handling

Finite State Machine (FSM) example:

```
Initialization
  Notif.  Cryo  Checks

Gradient
  FF  check A&P  SP adjust.  FB

Cavity
  Piezo  QL  Tuners  Limiters  Quench

Beam
  BLC  LFF  BBF

System
  Energy  Diag.  Perf.
```
LLRF and Operation (2/2)

- RF station ON/OFF
- Finite State Machine
- Exception handling
- Operator interface GUI
- Alerts / warning visibility

Intuitive GUIs
Layered complexity
Explicit alarms
Panel navigation
Complexity abstraction
Concentration of relevant data
Same data, different representation

- Automation
LLRF and Cavity Resonance Control

➤ Tuner motor
  - Tuning
  - Detuning
  - Cool down / warm up
  - Piezo relaxation

➤ Piezo
  - Microphonics
  - LFD compensation
  - Cavity fine tuning
  - Piezo capacitance measurement

➤ Gun
  - Cooling (water temperature)
  - Flat-top length regulation

Piezo capacitance (a) and resistance (b) during cool down
LLRF and Beam (1/2)

- BAM, BCM → BBF
- Toroid → BLC
- Beam phase
- Beam transients → channel alignment

Channel delay alignment using single bunch transients
LLRF and Beam (2/2)

- BAM, BCM $\rightarrow$ BBF
- Toroid $\rightarrow$ BLC
- Beam phase
- Beam transients $\rightarrow$ channel alignment
- Beam profile $\rightarrow$ TDS, BC
- Beam energy $\rightarrow$ VS calibration
- Beam loading $\rightarrow$ $Q_L$ adjustments
- …

Reference: J. Branlard et al. “LLRF Automation for the 9mA ILC Tests at FLASH” LINAC 2012, Tel Aviv, Israel

(a) short beam default $Q_L$
(b) short beam optimized $Q_L$
(c) full beam optimized $Q_L$
LLRF and Diagnostics (1/2)

- Beam diagnostics (BPM, BLM, BAM, toroid, etc..)
- LLRF diagnostics
  - Performance (intra- inter-train)
  - Heat load estimation
  - Virtual probe

Virtual probe calculation
LLRF and Diagnostics (2/2)

> Beam diagnostics (BPM, BLM, BAM, toroid, etc.)

> LLRF diagnostics

- Performance (intra - inter - train)
- Heat load estimation
- Virtual probe

> HOM

> Radiation

> System health

- Temperature
- Fan speed
- Piezo
- CPU load
- …
LLRF and…

> Controls
  - Real time capabilities
  - DAQ
  - Front-end (controls)
  - Middle layer (Diagnostics)

> Machine Protection
  - Interlocks (MPS)
  - Cryo OK?
  - LLRF alarm

> RF Couplers
  - QL control (motor / 3 stub tuners)
  - Conditioning
  - Interlocks (e-, light)
  - Heating

> Personnel Protection
  - Personnel interlock
  - RF permit

> Experiments
  - RF Reference distribution
  - Beam stability (BAM, energy)

> …
PART II

INTERFACES TO LLRF

LLRF FOR LARGE SCALE ACCELERATORS
Mass production

- Specifications
- Call for tender
- Documentation
- 3D models
- Test procedure with firmware
- Non-conformity report
- Etc…
6 ADC saturation level

ADC saturation levels at the phase of the connection have been later passed the tests.

<table>
<thead>
<tr>
<th>Channel No</th>
<th>Saturation Level [dBc]</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.247151</td>
<td>OK</td>
</tr>
<tr>
<td>2</td>
<td>0.345275</td>
<td>OK</td>
</tr>
<tr>
<td>3</td>
<td>0.345275</td>
<td>OK</td>
</tr>
<tr>
<td>4</td>
<td>0.345275</td>
<td>OK</td>
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<td>5</td>
<td>0.345275</td>
<td>OK</td>
</tr>
<tr>
<td>6</td>
<td>0.345275</td>
<td>OK</td>
</tr>
<tr>
<td>7</td>
<td>0.345275</td>
<td>OK</td>
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<tr>
<td>8</td>
<td>0.345275</td>
<td>OK</td>
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<tr>
<td>9</td>
<td>0.345275</td>
<td>OK</td>
</tr>
<tr>
<td>10</td>
<td>0.345275</td>
<td>OK</td>
</tr>
</tbody>
</table>

Table 6: Channel saturation level at EBNI connector phase.

7 ADCs spectral purity

The operation's frequency dependence has been measured. ADCs have passed the tests.

<table>
<thead>
<tr>
<th>Channel No</th>
<th>Frequency [MHz]</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>146.511028</td>
<td>OK</td>
</tr>
<tr>
<td>2</td>
<td>146.511028</td>
<td>OK</td>
</tr>
<tr>
<td>3</td>
<td>146.511028</td>
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<td>4</td>
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<tr>
<td>5</td>
<td>146.511028</td>
<td>OK</td>
</tr>
<tr>
<td>6</td>
<td>146.511028</td>
<td>OK</td>
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<tr>
<td>7</td>
<td>146.511028</td>
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<td>8</td>
<td>146.511028</td>
<td>OK</td>
</tr>
<tr>
<td>9</td>
<td>146.511028</td>
<td>OK</td>
</tr>
</tbody>
</table>

Table 5: ADCs frequency power measurement.

8 Channel-to-channel crosstalks

Channel-to-channel crosstalks have been measured. DUT has passed the tests.
LLRF FOR LARGE SCALE ACCELERATORS

Installation

- Procedure
- Check list
- Labelling
- Device tracking
LLRF FOR LARGE SCALE ACCELERATORS

> Large channel integration

outer-rack cabling

inner-rack cabling
> Remote “everything”

- System health **monitoring**
- System **upgrades** (FW / SW)
- **Management** (on / off / swap)

Radiation monitoring in tunnel

Temperature monitoring

- Increased CPU load
- Maintenance

1 month
LLRF FOR LARGE SCALE ACCELERATORS

> Remote “everything”
  - System health **monitoring**
  - System **upgrades** (FW / SW)
  - Management (on / off / swap)

> Redundancy
LLRF FOR LARGE SCALE ACCELERATORS

> Automation

- For operation
- For machine protection

Exception Handling
Automation Priorities

Frequency tuning / detuning
Bandwidth control
Diagnostics
Quench
Startup/shutdown
Calibration
Performance...

Cavity bandwidth control

Cavity resonance control

<table>
<thead>
<tr>
<th>General</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
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<tbody>
<tr>
<td>Enable</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
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<table>
<thead>
<tr>
<th>ALL ON</th>
<th>STOP</th>
<th>STOP</th>
<th>STOP</th>
<th>STOP</th>
<th>STOP</th>
<th>STOP</th>
<th>STOP</th>
<th>STOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL OFF</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>C2,ACC7</th>
<th>C3,ACC7</th>
<th>C4,ACC7</th>
<th>C5,ACC7</th>
<th>C6,ACC7</th>
<th>C7,ACC7</th>
<th>C8,ACC7</th>
<th>C9,ACC7</th>
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</thead>
<tbody>
<tr>
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<td>00000000</td>
<td>00000000</td>
<td>00000000</td>
<td>00000000</td>
<td>00000000</td>
<td>00000000</td>
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</tbody>
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<table>
<thead>
<tr>
<th>C2,ACC6</th>
<th>C3,ACC6</th>
<th>C4,ACC6</th>
<th>C5,ACC6</th>
<th>C6,ACC6</th>
<th>C7,ACC6</th>
<th>C8,ACC6</th>
<th>C9,ACC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000000</td>
<td>00000000</td>
<td>00000000</td>
<td>00000000</td>
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<td>00000000</td>
<td>00000000</td>
<td>00000000</td>
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</tbody>
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<table>
<thead>
<tr>
<th>AVG V0L</th>
<th>245267</th>
<th>2477137</th>
<th>2770227</th>
<th>2595508</th>
<th>2956037</th>
<th>2979049</th>
<th>2664477</th>
<th>2808423</th>
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</table>

<table>
<thead>
<tr>
<th>VI error[TH]</th>
<th>16.25</th>
<th>12.43</th>
<th>7.66</th>
<th>12.12</th>
<th>1.47</th>
<th>0.59</th>
<th>4.55</th>
<th>3.72</th>
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<table>
<thead>
<tr>
<th>Motor status</th>
<th>ready to be moved</th>
<th>ready to be moved</th>
<th>ready to be moved</th>
<th>ready to be moved</th>
<th>ready to be moved</th>
<th>ready to be moved</th>
<th>ready to be moved</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Motor pos. SP</th>
<th>57972</th>
<th>279552</th>
<th>81392</th>
<th>167024</th>
<th>242652</th>
<th>331724</th>
<th>209052</th>
<th>194507</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Motor current pos.</th>
<th>57972</th>
<th>279552</th>
<th>81392</th>
<th>167024</th>
<th>242652</th>
<th>331724</th>
<th>209052</th>
<th>194507</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Disturbing curves</th>
<th>0</th>
<th>-200</th>
<th>-400</th>
<th>-600</th>
<th>-800</th>
<th>-1000</th>
<th>0</th>
<th>200</th>
</tr>
</thead>
</table>

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QUESTIONS?

THANK YOU!

Photo courtesy: D. Noelle, DESY
RADIATION MEASUREMENTS: first results at FLASH

Counting Single Event Upsets (SEU) on SRAM

- **ACC1 / 39**
  - 1068 SEUs detected in from 2014-02-10 21:36:30 to 2014-03-11 10:46:30
  - Absorbed dose: 677.25 mGy
  - SEU to Gy CC: 0.5405 mGy/SEU
  - Analyze settings: Start date: 10 February 2014, hour: 21, 1 month
  - Number of data point in wanted period: 1065
  - Absorbed dose plot: X 20

- **ACC23**
  - 48 SEUs detected in from 2014-02-10 21:35:29 to 2014-03-11 10:46:29
  - Absorbed dose: 25.94 mGy
  - SEU to Gy CC: 0.5405 mGy/SEU
  - Analyze settings: Start date: 10 February 2014, hour: 21, 1 month
  - Number of data point in wanted period: 49
  - Absorbed dose plot: X 20

1 month

1.85 SEU / hour

0.09 SEU / hour

Courtesy T. Kozak
LLRF FOR LARGE SCALE ACCELERATORS

> Large channel count
HIGH LEVEL SERVERS (example)

> INTRA-STATION communication

> INTER-STATION communication

Courtesy S. Pfeiffer