RF considerations for SwissFEL

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in behalf of the PSI RF group

Workshop on Compact X-Ray Free Electron Lasers
19.-21. July 2010, Shanghai

Agenda

- Introduction
- RF-Gun Development
- C-band development
- Summary
Baseline Layout SwissFEL

SwissFEL Injector
S-Band 2996.8 MHz (21\texttimes f_{c})
X-Band 11995.2 MHz (84\texttimes f_{c})

Main LINAC
C-Band 5712 MHz (40\texttimes f_{c})

Tolerance ballpark:
amplitude: $10^{-5}$ - $10^{-4}$
phase: 0.03°

250 MeV Injector RF Systems

CTF gun
S-band
35 MW - 4.5 \mu s
Klystron TH2100E

INFN 1 cell deflector 1

2\pi/3 TW
4 m long

S-band
Mode 1: 45 MW - 4.5 \mu s
Mode 3: 60 MW - 1.2 \mu s
Klystron TH2100L

X-band
50 MW - 1.5 \mu s
XL5 - SLAC

INFN 5 cell deflector 2

S-band
7.5 MW - 4.5 \mu s
TH 2157
## SwissFEL project

### Time Line

#### Schedule SwissFEL Phase 1 & 2

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RF R/D Projects for SwissFEL

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<th>Project</th>
<th>Status</th>
<th>Due</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>S-band RF Gun</td>
<td>Reviewing mechanical drawings</td>
<td>2011</td>
<td>LCLS, PHIN</td>
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<tr>
<td>X-band acc. structure</td>
<td>Machining cups</td>
<td>2010</td>
<td>Collaboration with CERN</td>
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<td>C-band acc. structure</td>
<td>Brazing tests, finalizing RF design</td>
<td>2013</td>
<td>Collaboration with INFN</td>
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<td>C-band pulse compressor</td>
<td>Mechanical design started</td>
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<td>Collaboration with INFN</td>
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<td>C-band deflecting cavity</td>
<td>Not yet started</td>
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<td>C-band modulator</td>
<td>Procurement in progress</td>
<td>2011</td>
<td>SCN</td>
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<tr>
<td>C-band klystron</td>
<td>Procurement in progress</td>
<td>2011</td>
<td>Toshiba</td>
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<tr>
<td>LLRF</td>
<td>S-band prototype ready</td>
<td>2011</td>
<td>PSI development</td>
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Pulsed DC Gun

- Charge: 180 pC
- Energy: 5.7 MeV
- $\epsilon_x$: 0.5 μm
# C-band LINAC Module

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<tr>
<th>Main LINAC</th>
<th>#</th>
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<tr>
<td>LINAC modules</td>
<td>26</td>
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<tr>
<td>Modulator</td>
<td>26</td>
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<tr>
<td>Klystron</td>
<td>26</td>
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<td>Pulse compressor</td>
<td>26</td>
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<tr>
<td>Accelerating structures</td>
<td>104</td>
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<tr>
<td>Waveguide splitter</td>
<td>78</td>
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<tr>
<td>Waveguide loads</td>
<td>104</td>
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</table>

- **Main LINAC**
  - LINAC modules: 26
  - Modulator: 26
  - Klystron: 26
  - Pulse compressor: 26
  - Accelerating structures: 104
  - Waveguide splitter: 78
  - Waveguide loads: 104

- **RF Design**
  - Const. gradient structure with J-type coupler (5712 MHz, 2π/3).
  - Detuning of the structure might be necessary (two bunch operation).

- **Mechanical / Fabrication Concept**
  - No tuning of the structures (→ precision manufacturing).
  - Conventional joining technology (e.g. brazing instead of diffusion bonding).
  - Develop technology in house and together with external company.
Brazing Development Steps

1. Brazing of two “regular” cups
   → evaluate brazing parameters
   → check mechanical precision
2. Brazing of two “UP” cups
   → check RF precision
3. Brazing of a stack of “UP” cups (max. length 800 mm)
   → check RF properties
   → check cup alignment
   → RF high power tests (using mode launchers)
4. Brazing of full structure (cannot be done at PSI)
   → check everything
RF Pulse Compressor

S-Band Barrel Open Cavity (BOC), CERN

Energy gain vs. bunch arrival time

P_{RF,Klystron} = 41 MW

18 / 25
Workshop on compact XFEL, Shanghai 19.07.2010
**Klystron: Toshiba E37202**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Frequency</td>
<td>5712 ± 5 MHz</td>
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<tr>
<td>Beam Voltage</td>
<td>370 kV</td>
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<td>Cath. Current</td>
<td>344 A</td>
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<tr>
<td>Efficiency</td>
<td>43 %</td>
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<tr>
<td>RF drive</td>
<td>500 W</td>
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<td>RF output pk.</td>
<td>50 MW</td>
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<tr>
<td>RF output av.</td>
<td>12.5 kW</td>
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<tr>
<td>Beam perv.</td>
<td>1.5 μ AV^{3/2}</td>
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<td>Pulse rep. rate</td>
<td>60 Hz</td>
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Will buy E37202 to be able to start high power testing in the C-band RF test stand. Klystron will arrive in spring 2011.

Need upgraded klystron for a pulse repetition rate of 100 Hz. 100 Hz klystron should be ready in early 2012.

Used in SPring-8

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**Modulator: ScandiNova**

First operational experience in the 250 MeV injector indicates usefulness of ScandiNova solid state modulators.

Will buy ScandiNova modulator for C-band RF test stand. Should be operational in spring 2011.
• RF gun (FINSS)
  - hw: clone of DESY type digital LLRF system (SIMCON-DSP)
  - no pulse-to-pulse feedbacks so far — try to understand the measured data first!

• new digital LLRF system for the 250 MeV injector:
  ▪ hardware
    - common digital hw, VME controls interface; frequency specific front-ends (3 GHz, 12 GHz)
    - systems (S-band) ready for commissioning
    - digital hw: FPGA (Virtex5) processing board with 16 bit/125 MS/s ADC, DAC
    - 12 GHz RF/E development: design phase started
  ▪ software
    - controls integration completed
    - 10 Hz rep. rate for beam operation
    - 100 Hz rep. rate for modulator tests
      (data transfer to ctrl. system reduced to 10 Hz)
    - pulse-to-pulse feedbacks in preparation
  ▪ performance in lab (S-band) (detection bandwidth: 7 MHz)
    \[
    \sigma_{\text{ampl.}} \approx 5 \times 10^{-4} \\
    \sigma_{\text{phase}} \approx 0.03^\circ
    \]

  performance: \( \sigma_{\text{ampl.}} \approx 5 \times 10^{-4} \)  
  \( \sigma_{\text{phase}} \approx 0.03^\circ \)

  performance: \( \sigma_{\text{ampl.}} \approx 1.2 \times 10^{-4} \)  
  \( \sigma_{\text{phase}} \approx 0.014^\circ \)
First measurements

Klystron gun (FINSS)
- Pulse-to-pulse RF phase of the incident power during 10 minutes (10 Hz rep. rate)
- Phase of every pulse averaged over 400 ns (40 samplings)
- no RF feedback so far!
  In blue: filtered data for future RF feedback
- 2 min. period phase oscillation: correlated with water temperature oscillations
  • slow phase drift: correlated with LLRF electronics ambient temp.

Phase Forward Power \[°\]  
Gun Temp. \[°C\]

Reference Phase \[°\], 3 GHz
LLRF Ambient Temp. \[°C\]

Future strategy:
- better ambient temperature stability and/or temp. stabilized LLRF electronics necessary
- reference tracking
- beam based feedbacks (later stage)

RF gun: RF pulse-to-pulse stability

Phase stability \[°\] (forward power)

Amplitude stability [relative] (forward power)

Max. pulse to pulse phase jitter: 0.02° (rms)
Max. pulse to pulse amplitude jitter: 0.019% (rms)

Pulse-to-pulse data: standard deviation over the last 40 pulses (rep. rate 10 Hz).
At each pulse the data is averaged over 400 ns.

- klystron high voltage stability: < 3.6⋅10⁻⁵ (rms)
- pulse-to-pulse ampl. jitter not yet understood (pre-amplifier?)
Summary

- RF group is currently installing and commissioning the S-band linac in the SwissFEL injector test facility.
- Development, engineering and fabrication of an S-band RF gun is in progress.
- Design, engineering and fabrication of a C-band linac structure and a BOC RF pulse compressor is in progress.
- Setup of a dedicated C-band test stand has been started (should be operational mid 2011). It is foreseen to test a complete C-band linac module.
- First PSI LLRF system (S-band) is operational. C- and X-band are still missing.
- Development of an optical timing/synchronisation system is in progress (not covered in this talk).