RF Phase Reference Distribution for the European XFEL

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For the RF Synchronization Team
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Introduction – European XFEL

- 3.3km long machine
- Several thousands of digital, RF and optical devices to synchronize
- Most critical subsystems located in injector area
Short Summary of Requirements

LO, precise clocks and other locally generated and distributed signals not included here but also of concern for the RF distribution

- 1300 MHz @ injector (timing, MLO, ....)
- 20 x 1300 MHz, +10 to +21 dBm
  * 5 to 300 fs jitter
  * 100 fs drift
- 10 x 216 MHz,
  * 250 fs jitter
  * 10 ps drift
- 8 x 10 MHz

- 21 x 1300 MHz (+ 3 spare), +21 dBm
  * 50 fs jitter
  * 1 ps drift
- 21 x 216 MHz,
  * 250 fs jitter
  * 10 ps drift
- 21 x 10 MHz

- 5 x 1300 MHz, +10 dBm
  * 100 fs to 1 ps jitter
  * 10 ps drift
- 137 x 216 MHz,
  * 250 fs jitter
  * 10 ps drift

- Together more than 220 outputs
- Main reference signal frequency is 1300 MHz
- Required high availability (best would be no breaks in operation over the life time of XFEL)
Basic Assumptions

- Single frequency (1.3 GHz) Master Oscillator (see talk by. Ł. Zembala on Friday morning)

- Direct 1300 MHz distribution links from the Master Oscillator to injector devices and along the LINAC

- Other frequencies generated locally

- 216 MHz distribution along undulators
Overall Synchronization System Concept

- Three complementary systems (compromise between performance and cost)
  - Optical synchronization: sub-10fs (jitter, drift) performance, 12 links
  - RF Coaxial distribution: sub-100fs (jitter) and sub-1ps (drift) performance, interferometers, local distribution (44 links, ~260 reference outputs)
  - Timing system
- All systems phase synchronized to the RF Master Oscillator.
Coax cable links combined with high-performance optical links

Coax cable distribution: robust and reliable but loss limits distribution distance

The RF signal phase will be precisely adjusted to the optical reference at each of 12 outputs of the optical system

In case of optical system failure, the coax distribution should still deliver signals but with limited performance
> Basically the L2RF setup is a precise phase detector used to synchronize the RF signal to optical pulses

See paper TUPC33 at IBIC2013

Long term drift measurement

3.6 fs

Courtesy: T. Lamb
Coax Cable Based Distribution

<table>
<thead>
<tr>
<th>Cable (selected example)</th>
<th>LCF78-50JATC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>7/8”</td>
</tr>
<tr>
<td>Attenuation @ 1.3 GHz [dB/100m]</td>
<td>4.55</td>
</tr>
<tr>
<td>Phase drift @ 25 °C [fs/°C/m]</td>
<td>10 ÷ 25</td>
</tr>
</tbody>
</table>

- Phase drifts calculated for selected cables and for nominal operating temperature characteristic (data by Hans-Jörg Eckoldt) with span of 2°C
- Estimated values at section ends
- In worst case phase drift compensation by factor of ~70 is required — interferometer solution
- Target: drift suppression factor >150
Interferometer Link


- Performance limited by cable loss and coupler isolation

- Feasible distribution distances for the European XFEL up to:
  - 150m (7/8” cable, 1.3 GHz, 3 tap points)
  - 300m (7/8” cable, 1.3 GHz, 1 tap point)
Conditions for phase stabilization:

- Phase lock to MO at InCon (short at the end of the cable)
- Properly set distance between short and TapPoint \((L_1, L_2, L_3)\)
- Equal amplitude and phase of forward and reflected signals at TapPoint power combiner \((C_f, C_r)\)

- Very time consuming tap points adjustment
- Difficult to adjust in the E-XFEL tunnel (~70 Tap Points in total)
- Almost not feasible without automatic adjustment!
Automatic Interferometer Tap Point Adjustment

- Directional coupler C3 provides forward signal phase locked to the input signal at phase detector PD1
- Phase shifter PS3 simulates cable drifts
- Depending on switch positions the algorithm:
  1. Measures reflected signal amplitude and phase
  2. Sets forward signal amplitude and phase to match reflected signal
  3. Measures drift suppression factor
  4. Changes PS3 and repeats steps 1-3 until maximum drift suppression is found

Unpublished material. Prepared for publication
Basic Interferometer Components

- Careful RF design to minimize RF loss and phase drifts
- Compact PCBs, prepared for metal housings with humidity shielding and temperature stabilization
- Custom design of main line directional couplers for TapPoint (isolation >40 dB)
- Integrated diagnostics
Example of Automatic Adjustment Results

- Plot shows measured phase drift suppression factor vs phase shifter’s settings
- Software/firmware preparation and long term drifts tests are going on now

- Creating this plot is time consuming, but after 1st adjustment, it is possible to perform a fast fine adjustment whenever it is needed
Current Status of Interferometer Links

- Final test setup hardware ready
- Worked out detailed automatic adjustment procedure
- Waiting for firmware/software team to fix communication problems
- Very good results achieved so far

- Preparing final (mass production ready) PCBs including housings
Long Distance Distribution

- Designed detailed distribution scheme for the entire machine
- Cabling and patch panels are installed subsequently with cryomodules

Distribution example Master Oscillator to LINAC section L1)

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<tr>
<th>IM1</th>
<th>IM2.3</th>
<th>IM2.2</th>
<th>IM2.1</th>
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<tbody>
<tr>
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<td>eBPM-0</td>
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<td>94m</td>
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Hardware Production and Installation

- All interferometer and auxiliary hardware will be located in REFM boxes
- Worked out modular REFM box architecture
- Single design: several REFM boxes versions are configured by installing specified modules like InCon, TapPoint, Amplifier, ...

Example of distribution and REFM configuration (LINAC section L1)
Summary

- Designed distribution scheme
- Developed interferometers with automatic adjustment
- Interferometer hardware prototypes designed and tested
- Working on final PCB and housing versions
- Preparing REFM boxes and final production
- Cabling installation ongoing in the tunnel
- Preparing software for link operation
- All must run in 2016 …
Thank you for your attention!