MASTER OSCILLATOR FOR THE EUROPEAN XFEL

Ł. Zembala*, K. Czuba, B. Gąsowski, D. Sikora, WUT, Warsaw, Poland
H. Schlarb, H. Weddig, J. Branlard, DESY, Hamburg, Germany

Abstract

The reference signal outage causes breakdown of the synchronisation in the entire accelerator, which could result in a multi-day break in the operation. Therefore, the Master Oscillator (MO) for the European XFEL has to be redundant, in order to achieve extremely high reliability. The redundancy concept, which provides no interruption in the reference signal, requires phase coherence, fast RF switching and sustaining the RF power with a high-Q filter. These features allow to keep possible signal transitions smooth. Furthermore, the MO has to generate a 1.3 GHz signal of exceptionally good phase noise performance – jitter < 35 fs RMS integrated from 10 Hz to 1 MHz. One of the problems in the way are vibrations, which have to be properly isolated to avoid microphonics effects in oscillators. The proposed MO architecture and connection with the RF distribution system is described. A basic prototype is tested and results are presented.

RF SYNCHRONIZATION SYSTEM

The MO is a part of the RF synchronization system, which is responsible for generation and delivery of an RF phase reference signal to the systems along the entire European XFEL machine. The synchronization system is composed of three subsystems [1]: the MO, the Master Laser Oscillator (MLO) with sub-10fs stabilized optical fiber links [2, 3] and the coax cable based phase reference distribution system (PRDS). The MO is located in the begining of the machine (Injector area) and generates the reference signal to all accelerators components (Figure 1).

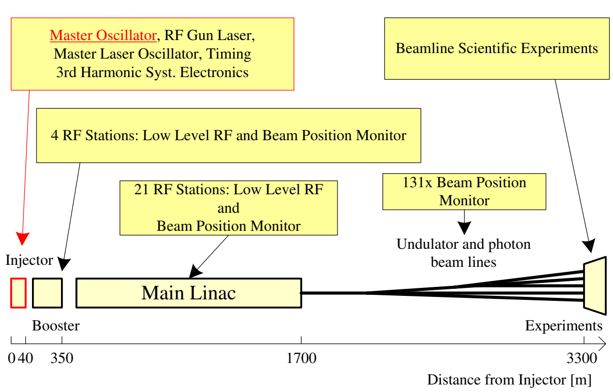

Figure 1: The MO and subsystems requiring RF reference signal in E-XFEL.

The MLO is phase-locked to the MO signal and provides laser light pulses to the length stabilized optical fiber links, but only to selected locations. In turn, sub-100 fs coax cable links distribute the signal to all locations in the machine. This paper describes the concept and preliminary performance of the MO system.

* lukasz.zembala@desy.de

REQUIREMENTS

The most important MO signal parameters are derived mainly from the EM field stability of the superconductive cavities [1]. However, the exact transfer from the EM field parameters to the reference signal parameters is unknown, so the requirements have to be provided indirectly by the systems, which use the MO signal. The most challenging signal parameters are dictated by the optical system. The other requirements come from: coax cable signal distribution (direct connection), Low Level RF (LLRF), timing system and special diagnostic systems.

In the large scale accelerator, such as E-XFEL, the phases alignment could be a multi-day process, so, for costs reasons, the risk of the reference signal loss has to be minimized. Therefore, the MO will be a redundant device. The most important MO's features are given in Table 1.

Table 1: List of the Most Important MO's Features

Feature	Reason
Redundancy	Downtime risk minimization
High freq. stability	Arrival time of electron bunch
Low phase noise	High EM field stability in accelerating cavities
Diagnostics	Simple fault locating
High amplitude stability	High EM field stability in accelerating cavities
Output power	Power to distribution links

Optical links require excellent long term frequency stability of min 10^{-11} for 1 s observation time. It allows to achieve the sub-10 fs link length stabilization [4]. The required short term stability (below 1 s) is described by the means of the phase noise as shown in Figure 2. The plot includes the jitter values calculated for each decade up to 10 MHz. The overall jitter value is 170 fs rms (in frequency range 1 Hz - 1 MHz).

The MO delivers total signal power of +32 dBm to 16 outputs. The amplitude stability of the signals is 1% p-p (long term f < 10 Hz) and 0.1% rms (short term f > 10 Hz).

The MO system will be built in number of 19" crates with integrated diagnostics and an on-line monitoring, that will allow to remotely confirm a proper reference signal generation or detect a broken part. For the data visualization the Distributed Object Oriented Control

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System (DOOCS) [5] is used, as it was done for the FLASH accelerator MO [6].

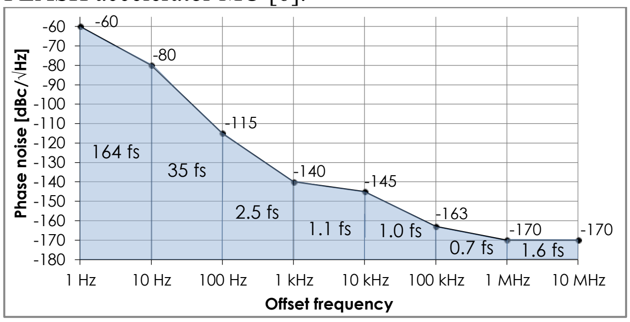

Figure 2: Phase noise requirements – rms jitter value integrated in each decade.

SYSTEM TOPOLOGY

The general block diagram of the system (Figure 3) consists of three equal 1.3 GHz Generation Channels (GC), an RF switch and a high-Q filter. The scheme is a fault tolerant design with two Hot Spares (HS) [7]. Three GCs are required to provide a self-test capability. The signal from the filter is splitted afterwards in a low-drift 16-way splitter. Most of the signals goes to the coax cable distribution, and the remaining ones are used as general purpose outputs.

Generation Channels

The GC is responsible for the generation of the stable reference signal of required power and stability. It consists of three main blocks: a primary reference, a 100 MHz synthesizer, and an 1.3 GHz synthesizer. Each device is hot-swappable.

The primary reference is a long term stable source. The GPS Disciplined Rubidium Oscillator (GPSD-Rb) guarantees the required moment-to-moment (1 s observ. time) stability and additionally it is immune to aging process [8]. The output frequency is 10 MHz, which is further multiplied by 10 in the 100 MHz synthesizer. The synthesizer reduces the phase noise of the input signal, by phase-locking of an ultra low noise crystal oscillator. The 1.3 GHz synthesizer consists of three main parts: vector modulator (VM), PLL with a dielectric resonator oscillator (DRO) and a high power amplifier (HPA). The VM works as a phase shifter and it is required for the redundancy concept (described in *Redundancy Concept* section). The 1.3 GHz DRO provides the phase noise floor level below 170 dBc/√Hz.

Redundancy Concept

The redundancy idea is presented in Figure 3. The design assumes, that the signal's performance stays the same, even if the fault occurs. This led to the solution with three equal permanently working GCs and a select switch. Such approach entails basic problems: signal absence during switching, failure detection, and channel synchronization.

A fast RF switch followed by a narrow band-pass filter (Q_L=3700) allows to avoid the signal's disappearance during the switching. The filter sustains the signal for about 300 ns (by then the power drops by 3 dB). Hence, 300 ns is the arbitrary time for three steps: fault detection, generation of switching signal, perform switching.

The critical failures has to be detected very fast. Each GC's output is tracked for unwanted amplitude drops and phase/frequency changes. To make phase comparison possible the signals have to be kept phase aligned. A slow phase feedback is introduced to compensate drifts between channels. The feedback utilizes VMs, which corrects phases in the HSs. The VM is placed in front of the 1.3 GHz synthesizer to minimize its non-linearities and phase noise influence on the output signal. A phase detector (in φ & A det.) works as a phase comparison unit. In order to make the phase detection possible, minimum three GCs are required to determine, which channel is failing.

The detection can be divided into three groups:
- fast phase detection,
- fast amplitude detection,
- slow frequency detection.

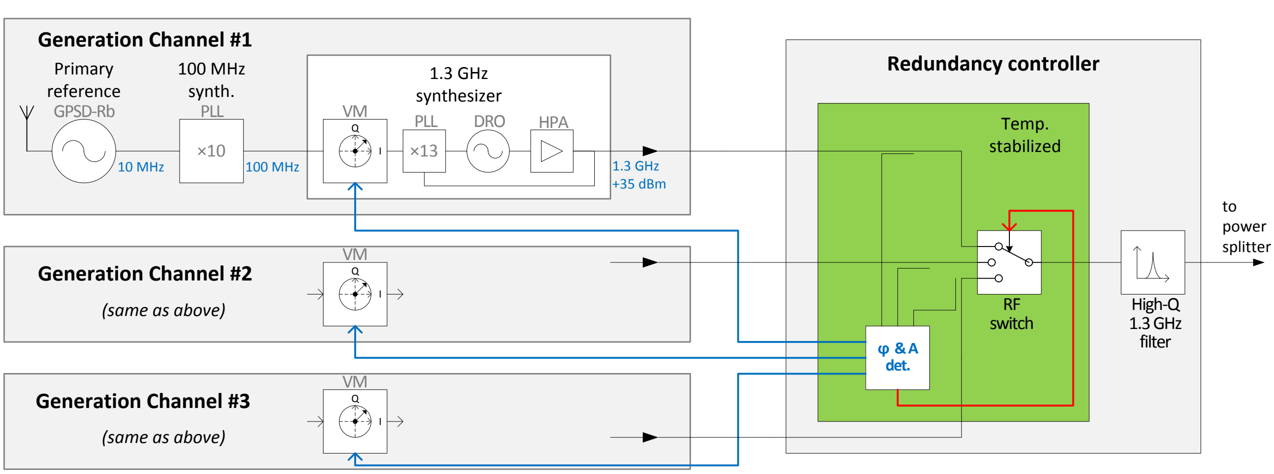

Figure 3: Block diagram of MO. Redundancy idea highlighted - drift compensation, phase and amplitude fail detection, fast RF switch and 1.3 GHz filter with high-Q resonator.

The first two detection types relies on the fast phase and amplitude detector block (φ & A det.). If any abnormality happened to the active channel the RF switch responds by switching to the Hot Spare.

Some faults result only in the long term frequency stability degradation, eg. loss of the Rb oscillator, and might not be visible to the phase detectors, due to the drift compensation feedback. One can detect it only by observing the status of the devices – slow frequency detection. The frequency instabilities worsen the machine parameters, but do not break the synchronization in the accelerator. Thus, the response does not have to be immediate – switch can be toggled on demand by the operator.

TESTS

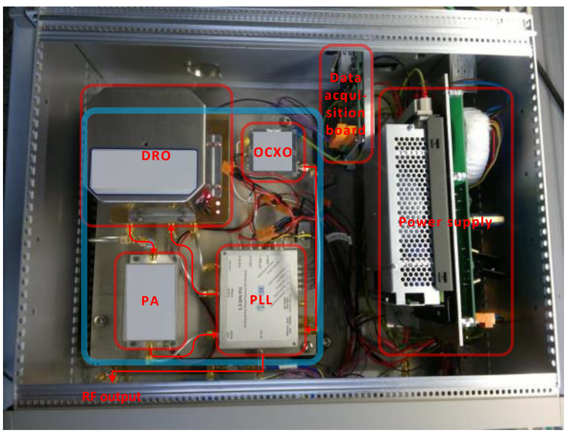

Figure 4: Prototype MO inside.

A very basic prototype of the MO was built to test the phase noise and vibration isolation performance of the simple design (Figure 4): low noise 1.3 GHz DRO phase-locked to the low noise 100 MHz OCXO (primary reference). The DRO is closed together with a power amplifier (PA) in the PLL.

The best achieved result of the source is presented in Figure 5 – the rms jitter from 10 Hz to 10 MHz is 30 fs. Further reasearch and tests are on-going.

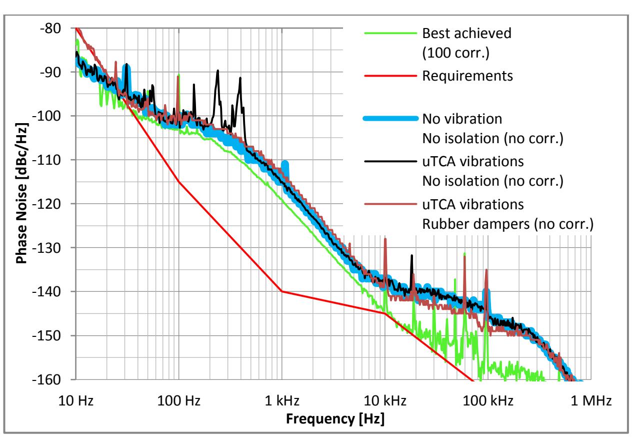

Figure 5: Phase noise under vibrations.

The vibration damping design (top view in Figure 4 – blue rectangle) consists of a heavy plate mounted on rubber dampers. The influence of a uTCA crate vibration to the prototype is presented in Figure 5.

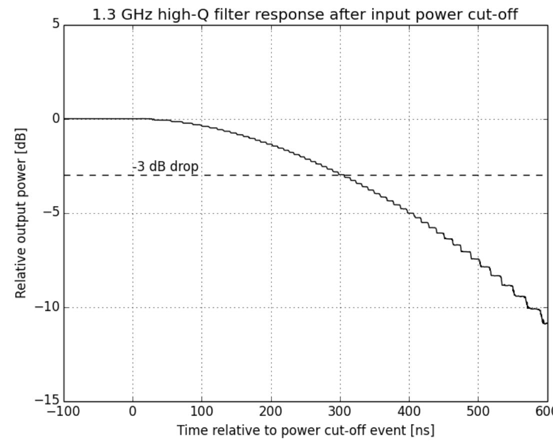

Figure 6: Power decay in high-Q 1.3 GHz filter.

A simple test with a specially designed high-Q filter (Q_L=3700) was done to validate the idea with power sustainment. The power decays by 3 dB in 300 ns (Figure 6) – the same as the assumed theoretical value.

CONCLUSION AND PLANS

The redundant, phase stable MO system concept was worked out. The GC channel prototype was build and signal generation performance was proven. Intensive construction work is on going to build the final system and commission system in the E-XFEL environment.

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