

THE RF PHASE REFERENCE DISTRIBUTION SYSTEM CONCEPT FOR THE EUROPEAN XFEL

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Abstract

At the European XFEL thousands of accelerator subsystems and components must be precisely phase synchronized for effective control of beam generation, accelerating fields, beam diagnostics, and exact timing of the user experiments. The synchronization scheme consists of a Master Oscillator system and a distribution system which must guarantee the required phase stability over the 3.4 km long from electron source to experiments. Design choices were based on the experience gained during the commissioning of the FLASH accelerator MO and phase reference distribution system. Analysis of phase noise and temperature sensitivity of the proposed system verify that the distributed signal phase stability requirements can be fulfilled for the injector and the main linac section of the XFEL. Optical synchronization techniques will improve the long term injector phase stability.

INTRODUCTION

The synchronization system for the XFEL facility consists of four subsystems: the RF Master Oscillator (MO) with RF Phase Reference Distribution System (PRDS), the optical synchronization system with Master Laser Oscillator (MLO) and the timing system.

The RF MO with PRDS will provide RF reference signals for the XFEL machine. The MLO will be phase-locked to the RF MO and will use optical fiber links with optical length stabilization to distribute light pulses. The MLO with stabilized optical fiber links is expected to provide excellent synchronization performance of up to 10 femtoseconds [1]. Due to high complexity and cost the usage of such links in XFEL will be limited to the synchronization in the injector, some diagnostics and the experiments. The reliability of optical links has not been proven, therefore redundant RF distribution links must be provided to critical XFEL subsystems.

The timing system will distribute trigger signals and event information necessary for synchronous machine startup and operation. The timing system will also be synchronized to the RF MO.

This paper covers the RF MO and PRDS concept for the XFEL.

REQUIREMENTS

Due to difficulty of modeling the sensitivity of beam energy, beam arrival time, and bunch compression to phase noise and phase drifts in the various accelerator sections a simplified model combined with experimental

results from the FLASH facility including the MO and PRDS [2] lead to the requirements for the XFEL.

The stability requirements for the 1300 MHz RF signal is summarized in Table 1. Requirements for other frequencies are similar.

Table 1: Stability Requirements at 1300 MHz

Location	Short Term Stability	Long Term Stability
Injector	10 fs	100 fs
Booster Section (L1 and L2)	30 fs	300 fs
Main Linac (L3)	100 fs	1 ps (1 second) 2 ps (1 hour) 10 ps (1 day)
Cavity BPM's	500 fs	1 ps

The XFEL synchronization system frequency scheme is based on decimal (important change comparing to the FLASH accelerator) system. The MO reference frequency will be equal to 10 MHz and will be multiplied by integer numbers (eg. x10, x130) to obtain other frequencies. Due to the length of the accelerator and the high cable losses at 1300 MHz a distribution frequency of 100 MHz was chosen. At the destinations all other needed frequencies such as 1300 MHz are derived from the 100 MHz.

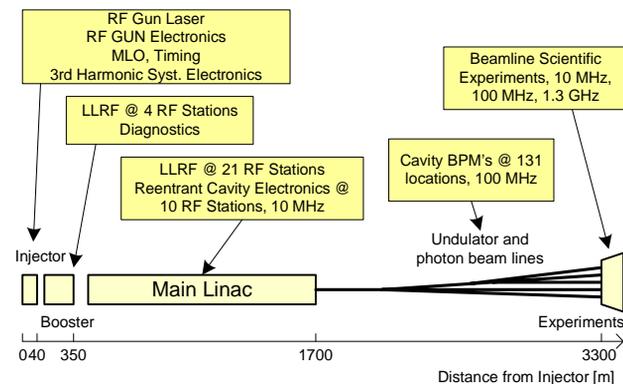


Figure 1: XFEL subsystems requiring RF phase reference signals.

The overview of the subsystems requiring RF phase reference signals is shown in figure 1. Only a few devices are located in the injector area but their stability requirements are the strongest, see (Table 1).

The main user of the phase reference signals is the LLRF system located at 25 RF Stations (RFS) in the injector area, booster and main linac. Each RFS will

consist of 4 cryomodules containing each 8 superconducting cavities. The LLRF system has therefore to process $4 * 8 * 3 = 96$ signals (field probe, forward and reflected power for each cavity) at each RFS. These signals are downconverted by mixers to an IF of 50 MHz. For this purpose a 1350 MHz phase stable LO signal has to be generated locally at each RF station. Additionally a frequency of 1300 MHz is needed for the input of the vector modulator to drive the klystron.

In the undulator section of the XFEL, about 130 cavity BPM's (used for diagnostic purposes of the beam position

within the beam line) are synchronized at 100 MHz. The synchronization accuracy is less demanding than for the linac but the distribution line will be about 1500 m long in up to 5 parallel photon tunnels.

In the experimental area, some photon experiments may require a better than 1 picosecond long term phase stable RF reference. The details still have to be worked out. Until now no detailed data can be provided on required frequencies, power levels and locations.

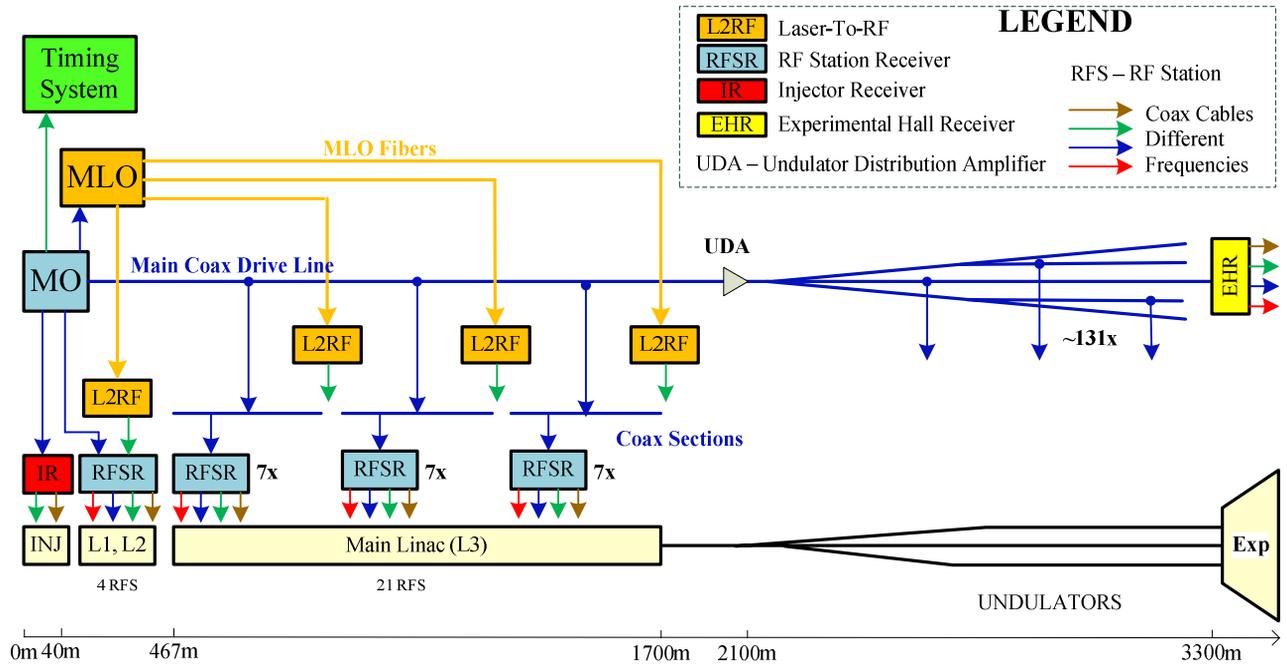


Figure 2: Simplified layout of the RF Phase Reference Distribution System in XFEL .

SYSTEM CONCEPT

The simplified layout of the XFEL RF PRDS is shown in figure 2. The 10 MHz reference signal and the 100 MHz distribution signal are generated in the MO. These signals will be delivered to the timing system and to the MLO.

RF Master Oscillator

The concept of the MO system is shown in figure 3. A 10 MHz atomic standard based clock is considered as the MO signal source. This frequency will be multiplied to 100 MHz with high performance phase-locked ovenized crystal oscillator. After power amplification this signal will be distributed along the XFEL. Uninterruptible power supplies and backup MO copy with automatic phase alignment will assure reliable system operation.

Injector Distribution

In the injector area signals will be provided to the RF-GUN control electronics and the RF-GUN laser. The performance of the optical links from MLO will support

fulfilling the stability requirements for the injector section. The RF MO signals will be provided to ensure redundancy and high system availability. It will be possible to switch between RF and optical phase references. This requires monitoring circuitry and phase calibrated switching between MO and MLO signals which will be realized in the Injector Receiver (IR).

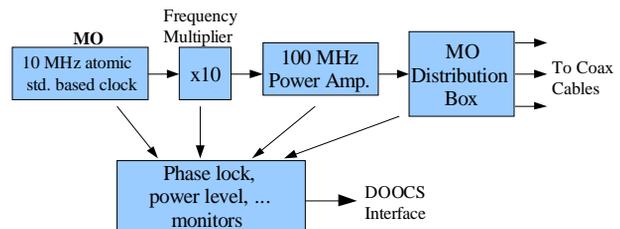


Figure 3: Master Oscillator system.

The RF phase reference system supports also the 3.9 GHz system (third harmonic cavity for bunch treatment) located in the proximity of the injector subsystems.

The injector area and the linac sections L1 and L2 will be supplied with RF reference signals by temperature

stabilized coax cables directly from the MO System (star type distribution). Due to increased stability requirements, for L1 and L2 the MLO optical link has also been foreseen to work together with the RF distribution.

Main Coax Drive Line

The Main Coax Drive Line (MCDL) will distribute the 100 MHz reference along the entire XFEL facility. In the main linac section pick-up points will be provided for coax cable sections. The MCDL will provide signal also to the experimental area with about 130 pick-up points in the undulator sections. The 100 MHz distribution frequency was selected as a compromise between RF loss in distribution cables and phase noise degradation in frequency multipliers.

A 7/8 inch diameter coaxial cable of the type LCF78-50J, is selected [3] for the RF reference distribution due to its exceptionally low temperature coefficient of its electrical length not exceeding 1 ppm in the temperature range +15 to +33 °C. Assuming a XFEL tunnel temperature stability of $\pm 1^\circ\text{C}^*$ per day, the peak phase drift in the MCDL would not exceed ± 5 ps from the MO up to end of the main linac. This value fulfills long term drift specs given in Table 1.

Section Distribution

In the main linac the RF distribution is divided into three sections. The limited length of each section (about 450 m) allows to implement the interferometric phase drift suppression in case of insufficient performance of the passive distribution. The RF signal phase at end of each section will be compared with a signal provided by phase stable optical links for the purpose of phase drift suppression monitoring. The assumed tunnel temperature stability of $\pm 1^\circ\text{C}$ will cause about 0.7 ps of long term phase drifts from the middle of a section to each end (about 225 m).

The section distribution lines will provide 100 MHz signals to 21 RF Stations (7 RF stations at each section).

Local Distribution and Frequency Generation

The generation and local distribution within one RF Station of the XFEL accelerator is the last part of the PRDS.

The generation of phase coherent signals will be done in the RF Station Receiver (RFSR) equipped with diagnostic devices. Following frequencies will be generated in the RFSR: 1300 MHz for LLRF System Vector Modulators, 1350 MHz for LLRF LO and 10 MHz for reentrant cavity BPM's and diagnostic purposes.

The LLRF signals will be provided from RFSR to racks based on the ATCA system [4]. The signal distribution performance (short and long term) within racks and ATCA crates is important for the entire LLRF system performance. Therefore the local signal distribution will be coupled with drift calibration system.

Calculations based on experience with the FLASH MO

*The tunnel temperature value and stability is still subject of discussion but rough calculation show values of about 1°C

show that for the RFSR a 100 fs level of short term signal phase stability can be reached easily (50 fs demonstrated at FLASH and 31 fs in laboratory). The long term stability of commercial phase coherent synthesizers does not exceed 3 ps per 12 hours in room temperature conditions. Values of about 1ps were demonstrated at FLASH MO. Therefore we assume that frequency generation electronics will contribute acceptable levels of phase drifts to the distribution system.

CONCLUSION

In this paper the concept of the RF MO and PRDS for the XFEL is presented. The 100 MHz signal generated at the MO will be distributed over the 3.4 km length to many receivers which generate the frequencies required by the subsystems. This frequencies are locally distributed over distances of up to 50 meters. Measurements at FLASH have shown that such a coaxial distribution system can support the required short and long term stabilities. High availability is achieved by the use of a passive cable distribution and some level of redundancy of the active components and use of the signals from the MLO links.

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