PERFORMANCE OF THE NEW MASTER OSCILLATOR AND PHASE REFERENCE SYSTEM AT FLASH

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Abstract

The Master Oscillator (MO) and phase reference system at FLASH must provide several RF reference frequencies to widely spread locations with low phase noise and small long term phase drifts. The phase noise requirement of the 1300 MHz reference is of the order of 0.1 deg. while the short and medium term phase stability are of of the order of 0.1 deg. and 1 deg. respectively. The frequency distribution system employs a temperature stabilized coaxial line for RF power distribution and a fiber optic system for the monitoring of phase drifts. Presented are the the concept, design and performance measured in the accelerator environment.

INTRODUCTION

The FLASH accelerator incorporates seven accelerating modules operating at 1300 MHz frequency. The Low-Level-Radio-Frequency (LLRF) control systems of these modules must control the accelerating field with defined precision in order to assure proper electron bunch acceleration. All LLRF control systems and many other FLASH subsystem require precise synchronization. The reference signals used for synchronization are generated in the MO System and distributed by a network of coax cable links – the phase reference distribution system. The design of the MO and phase reference distribution system was a very challenging task because of very tight requirements on the synchronization accuracy and the large distances of the accelerator. The short term phase stability is affected mainly by the phase noise appearing in frequency generation and distribution devices. Therefore phase noise issues have been analyzed before the system architecture was worked out. A significant source of long term phase drifts are temperature changes. A big effort was put in the MO and distribution system design in order to minimize the sensitivity of devices to temperature changes by temperature stabilization of the cables within the tunnel and housing the crates in climatized racks.

REQUIREMENTS

The MO and phase reference distribution system must generate signals with 10 different frequencies and distribute these signals to accelerator subsystems spread along the 300 meter long FLASH facility. The generated frequency values are: 50 Hz, 1 MHz, 9 MHz, 13.5 MHz, 27 MHz, 81 MHz, 108 MHz, 1300 MHz, 1517 MHz, 2856 MHz. The most important frequency is 1300 MHz, the operating frequency of the superconducting cavities. The stability requirements are specified for this frequency, as depicted in table 1. The values are the maximum phase errors allowed at each of the distribution system outputs and between any of these outputs.

Table 1: Stability requirements at 1300MHz

Stability within	Requirement	Values deg
Short term (phase noise)		
1 ms	0.1 ps	≈ 0.05
100 ms	0.3 ps	≈ 0.15
Long term (drifts)		
1 s	1 ps	0.467
1 hour	2 ps	0.936
1 day	≈ 10 ps	4.679

SYSTEM ARCHITECTURE

There are many issues that had to be considered before the final system architecture was proposed. For example the choice of MO type and frequency value, choice of distribution media type (coax cable or optical fiber) and choice of distribution frequency. It has to be decided whether all required frequencies should be generated at the MO and distributed along the FLASH linac or whether to distribute one frequency and generate all remaining frequencies locally, at the distribution destination devices. More detailed considerations on the choice of distribution system architecture can be found in [1].

It was decided that the FLASH distribution system will consist of 3 subsystems: the MO System, the coax cable distribution system and a fiber optic link for monitoring purposes. The block diagram is shown in figure 1.

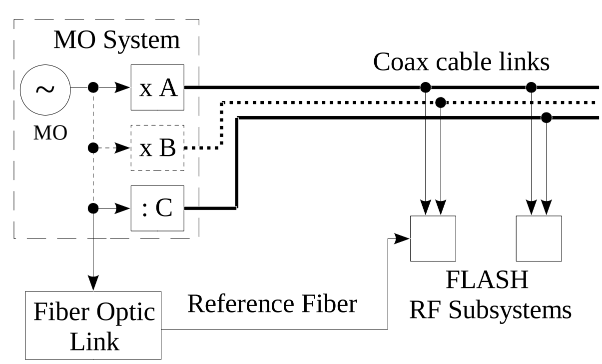

Figure 1: Conceptual layout of the FLASH RF phase reference distribution system.

The MO will be housed in three climatized racks in a climatized hut in the injector area. A 9 MHz OCXO is chosen as the reference oscillator. Most of the required frequencies are generated by a network of frequency multipliers and dividers located in the MO. The MO System block diagram is shown in figure 2. It was found [2] that the best phase stability of the generated signals can be obtained by phase locking of an 81 MHz VCXO (PLL x9) to the 9 MHz OCXO. All frequencies required for FLASH (except 108 MHz) are obtained out of the 81 MHz signal by frequency division or multiplication. The MO System components are equipped with signal performance monitoring devices. To improve the performance, the MO System except the high power amplifiers is powered from a battery buffered power supply. The subsystems of the MO are housed in 19” crates.

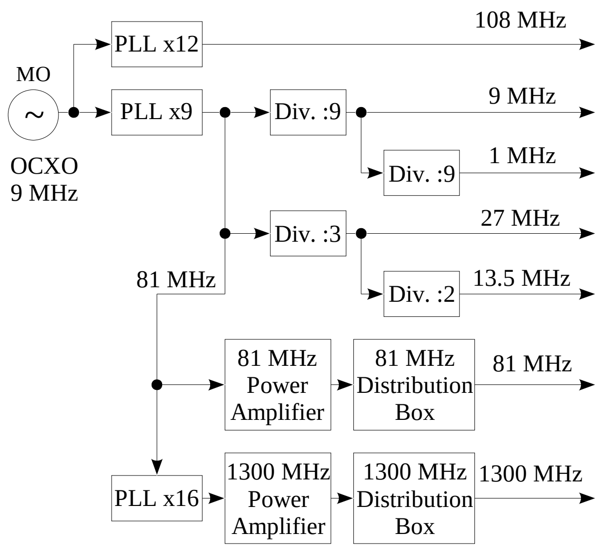

Figure 2: Master Oscillator System scheme.

All frequencies generated in the MO System are distributed by a network of phase stable coax cable links. Because of increasing cable attenuation with signal frequency and because of excellent temperature coefficient of phase length of about 1 ppm @ 20 °C, a Cellflex® 7/8 “ cable is chosen for 1300 MHz, 108 MHz, 81 MHz signal distribution. The ½“ Cellflex® cable is used for distributing lower frequencies. Temperature stabilization of ±0.5 °C was applied to the distribution cables in order to improve the long term signal stability. The expected phase drift values in the longest (300 m) 7/8” distribution cable are 5 ps and 0.22 ps respectively without and with temperature stabilization.

The third subsystem of the FLASH phase reference distribution system is a fiber optic link with an active phase stabilization. A detailed description is given in the next section.

PERFORMANCE

The accelerating field stability at FLASH depends on the performance of the field detection, modulator, klystron, LLRF control system itself, cavity microphonics, and the accelerator environment as well as on the noise and drift performance of the MO [4]. Figure 3 shows the single sideband (SSB) phase noise of two different frequencies at 1300MHz and 81MHz of the MO.

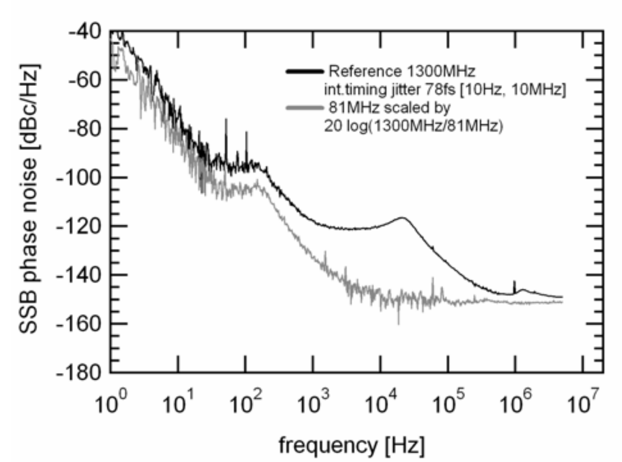

Figure 3: Measured MO phase noise spectra

With an integrated timing jitter of 78fs within the measurement bandwidth of 10Hz to 10MHz the required short term stability for FLASH is fulfilled. Except drifts from the MO itself of about 400fs/ °C at 1.3GHz, caused by internal phase detectors, the long term stability of the synchronization system at FLASH is given by the phase reference distribution system. For this, the phase drift of a 80m Cellflex® 7/8“ cable along FLASH is measured by using a network analyzer R&S ZVR. The phase of the measured S11 parameter over 12 hours of the cable without temperature stabilization is shown in Figure 4 and determined by 0.8ps , respectively 0.4° at 1.3GHz for back and forth propagation along cable.

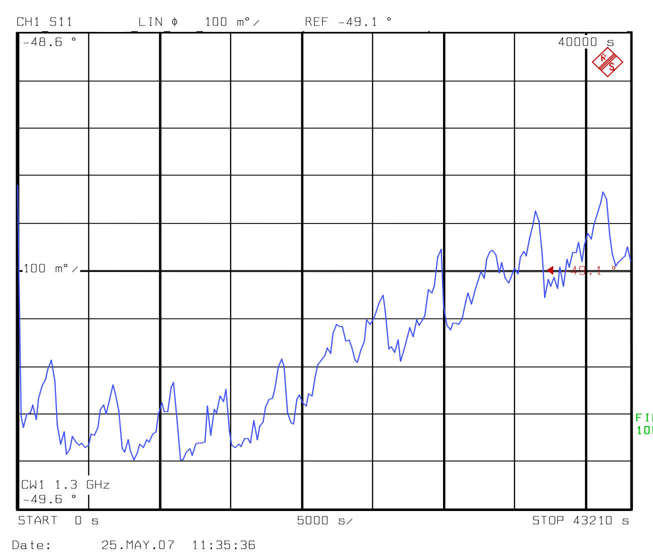

Figure 4: Phase drifts of a 80m Cellflex® 7/8 “ cable

The amplitude stability during the same measuring time was approximately 0.015dB. Repetitive short term phase variations are caused by temperature fluctuations from the climated temperature controlled injector area of the accelerator acting on a short part of a 3/8 " cable. Taken temperature measurements ΔT_i of N uniformly distributed sensors with distances ΔL_i along the cable and the measured cable temperature coefficients $c_{TK,i}$ into account the estimated phase drift over the measuring time is given by

$$\Delta t = 2\frac{\sqrt{\varepsilon_r}}{c_0}\sum_{i=1}^{N} c_{TK,i}(T)\Delta L_i \Delta T_i \approx 0.46\,ps$$

with $N = 11$, $\Delta T_i = \pm 0.5^o C$, $\Delta L_i = 7.3m$, $\varepsilon_r \approx 2.56$, which is roughly in accordance with the measured value. The performance of the fiber link with active stabilization is described now. A prototype of the link was designed and tested [3].

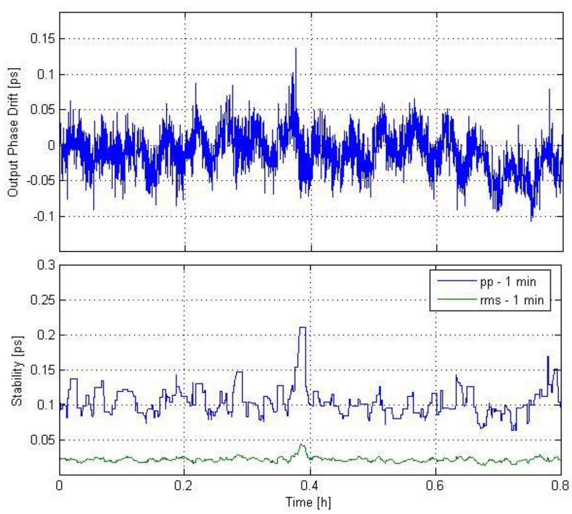

Figure 5: Performance of the Fiber Optic Link

A result is shown in Figure 5: The upper plot shows the phase deviations of the 1300 MHz RF signal at the link output after it was distributed over 5km. This data was then used for calculation of the phase stability over the time range of one minute (sliding time window) shown in the lower plot. During one minute a peak-peak stability of <200fs and an rms stability of <50fs was achieved, throughout the entire measurement.

These results make the fiber optic distribution link an excellent tool for monitoring the long term phase drifts of RF signals at remote places (several km) along the accelerator.

CONCLUSION

In this paper, the short term and long term stability of the master oscillator and phase reference system for FLASH is presented. With an integrated timing jitter of 78fs of the Master Oscillator operating at 1.3GHz the required short term stability for FLASH is fulfilled. A phase drift of 0.8ps is measured for a 80m Cellflex® 7/8" cable without temperature stabilization, which fulfill the required long term stability for FLASH. To verify the long term stability in the accelerator a fiber optic link with active phase stabilization was designed and tested. The long term phase stability operating at 1.3GHz was about 0.2 ps (peak-to-peak) during 100 hours and 50fs (peak-to-peak) over one minute duration. The timing requirements for the planned X-ray Free-Electron-Laser (XFEL) are much more sophisticated with a short term stability of about 10fs(rms) and long term stability of 20fs(rms) for the injector sections. The requirements for the main linac sections are relaxed by a factor of 10 compared to the injector. An active temperature stabilization of a local high frequency synchronization system including temperature sensitive subcomponents e.g. phase detectors, cables and active amplifiers seems to be complicated and expensive. Especially for the injector sections the local high frequency timing synchronization sections has to provide the required short term stability. The fiber optic links have to provide the excellent long term stability, as presented. In addition, drift properties of high frequency phase detectors and stabilized cables have to be improved using self-calibration and reflectometer techniques.

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