TIMING AND SYNCHRONIZATION FOR THE APS SHORT PULSE X-RAY PROJECT*

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Abstract

The Short-Pulse X-ray (SPX) project, which is part of the APS upgrade, will provide intense, tuneable, high-repetition-rate picosecond x-ray pulses through the use of deflecting cavities operating at the 8th harmonic of the storage ring rf. Achieving this picosecond capability while minimizing the impact to other beamlines outside the SPX zone imposes demanding timing and synchronization requirements. For example, the mismatch between the upstream and downstream deflecting cavities' rf field phase is specified to be less than 0.077 degrees root mean squared (rms) at 2815 MHz (~77 femtoseconds). Another stringent requirement is to synchronize beamline pump-probe lasers to the SPX x-ray pulse to 400 femtoseconds rms. To achieve these requirements we have entered into collaboration with the Beam Technology group at LBNL. They have developed and demonstrated a system for distributing stable rf signals over optical fiber capable of achieving less than 20 femtoseconds rms drift and jitter over 2.2 km over 60 hours. This paper defines the overall timing/synchronization requirements for the SPX and describes the plan to achieve them.

INTRODUCTION

The APS SPX will use transverse deflecting cavities to produce high-repetition-rate picosecond x-rays [1]. This scheme imposes challenges in synchronizing deflecting cavity phase and synchronizing beamline lasers.

The deflecting cavities will operate at the 8th harmonic of the storage ring rf of 351.9 MHz or 2815 MHz. This harmonic will be distributed via phase-stabilized fiber links to LLRF controllers and beamline laser oscillators

REQUIREMENTS

The rf cavity phase and amplitude need to be controlled to a sufficient precision to prevent excessive orbit motion and maintain a stable short x-ray pulse. Table 1 lists the phase tolerances for the SPX cavity fields. Note that the 77 millidegree tolerance for phase mismatch between cavities is particularly challenging. In addition, it is required that beamline pump probe lasers be synchronized to the x-ray pulse to 400 femtoseconds rms.

To achieve the demanding requirements, the APS has entered into collaboration with the Beam Technology Group of Lawrence Berkeley National Laboratory to assist with the LLRF and timing/synchronization development. This team has many years of experience in LLRF controllers and precision synchronization systems. They have expended a great deal of effort over the years in developing a system capable of delivering a phase reference stable to the 10's of femtoseconds level. Their fiber link stabilization scheme forms the basis for SPX phase reference distribution.

Table 1: Phase Tolerances

Specification Name	RMS Value	Bandwidth
Common Mode Phase Variation	< 10.6 deg	0.01 Hz – 271 kHz
Phase Mismatch Between Cavities	< 77 millidegrees	0.01 Hz – 1 kHz
Phase Mismatch Between Cavities	< 280 millidegrees	1 kHz – 272 kHz

DESCRIPTION

Figure 1 shows a block diagram of the phase reference distribution system. Actively stabilized fiber optic links will be used to distribute a 2815-MHz phase reference to each location. The active phase stabilization will correct for drifts due to environmental effects. The LBNL scheme precisely measures the optical phase delay through a fiber using a heterodyne interferometer [2]. As shown in the figure, each stabilized link consists of two fibers, the reference fiber and the beat fiber. The heterodyne process, in which the original optical frequency is mixed with an optical frequency offset by a 110-MHz radio frequency, results in changes in optical phase being translated into identical phase changes in the 110-MHz rf beat note. One degree of phase change in the 1560-nm optical domain, which corresponds to 21 attoseconds, translates to 1 degree of phase change in the rf domain or 25 picoseconds. This results in approximately 6 orders rf magnitude leverage over direct measurement in the rf domain. The phase changes in the 110-MHz beat note are measured and used to correct for changes in fiber cable delay due to environmental effects, such as temperature.

LBNL has reported measured results of 19.4 fsec rms for a 2.2-km fiber over 60 hours and 8.4 fsec rms for a 200-m fiber over 20 hours [2]. The 19.4-fsec measurement for the 2.2-km fiber was a reduction by a factor of approximately 1000 compared to no correction.

The 2815-MHz reference and the local oscillator reference for LLRF will be generated from a 351.9-MHz

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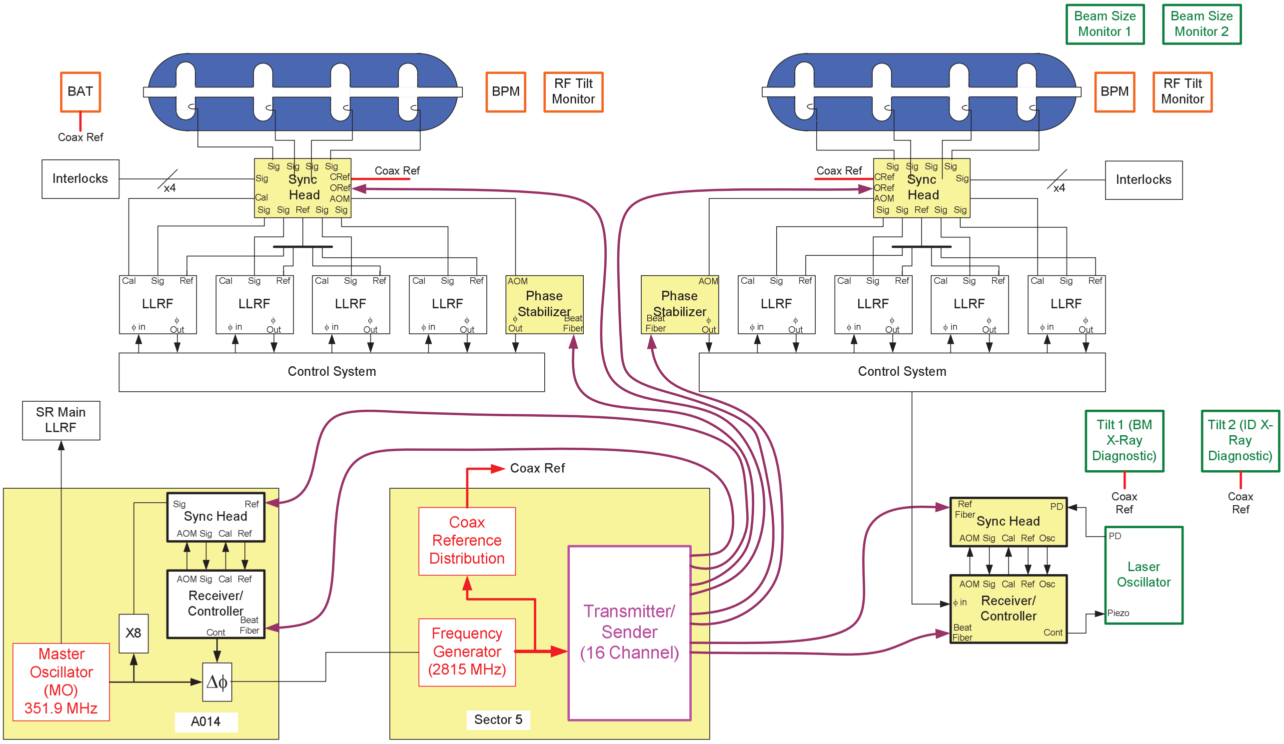

Figure 1: Block diagram of SPX timing/synchronization.

reference by a frequency generation chassis located at the SPX area. The 351.9-MHz reference will be transported from the APS master oscillator in A014 to the SPX area via a phase-stable coax cable. One of the optical links with a receiver/controller will compensate for drifts in the coax cable by controlling a phase shifter.

The fiber transmitter cw laser output is modulated by the 2815 MHz from the frequency generation chassis. The resulting amplitude-modulated optical signal is fanned out for distribution to the SPX LLRF systems and the beamline laser hutches. Each of the optical links is an independent heterodyne interferometer transporting the 2815-MHz reference as an amplitude modulation on the optical carrier. At each receiving end, the receiver measures changes in optical phase and uses this measurement to correct the phase of the received 2815-MHz signal

Each stabilized link receiver consists of two components, the link stabilizer and the sync head, as shown in Fig. 2. The sync head contains the acousto-optic frequency shifter, which shifts the optical frequency. The sync head is mounted as close as physically possible to the source of the signal to be stabilized, for example, the cavity field probe or laser oscillator. In the case of the SPX cavities, the sync head will be mounted inside the APS tunnel on top of the cryomodule.

As indicated in Fig. 2. drifts in the cable connecting the signal source, such as a field probe to the sync head, are not compensated, and therefore it is important to minimize the length of this cable. A calibration tone scheme is used to measure and compensate for drifts in the cables connecting the reference and signal to the link stabilizer [3].

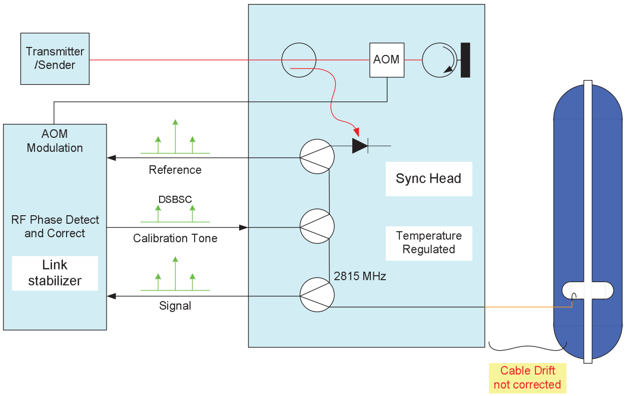

Figure 2: Sync head and link stabilizer.

To achieve the high level of phase stabilization relative to the 351.9-MHz master oscillator source, one of the stabilized links will be used to transport the 2815 MHz back to the master oscillator location. As shown in Fig. 1, the 2815-MHz phase will be compared to the 351.9 MHz multiplied by eight. The resulting error signal will be used to drive a phase shifter in the 351.9-MHz reference feed to SPX. This feedback will compensate for environmentally induced drifts in the copper coaxial cable transporting the 351.9-MHz master oscillator signal to the SPX area. Note that this feedback also compensates for drifts in the frequency generation chassis and the transmitter/sender.

Laser Oscillator Stabilization

Figure 3 shows the configuration for synchronizing the beamline laser oscillator. The sync head will accept an optical signal from the oscillator into a photodiode. The output of the photodiode will be split to a band-pass filter and a low-pass filter. The band-pass filter selects a harmonic of the oscillator corresponding to the 2815-MHz reference. This would be the 32nd harmonic in the case of an 88-MHz laser oscillator. The phase of this harmonic is locked to the reference phase by feedback to the piezo in the laser oscillator. The low-pass filter output is used by the link stabilizer to set the phase of the oscillator to correspond to the ring revolution fiducial.

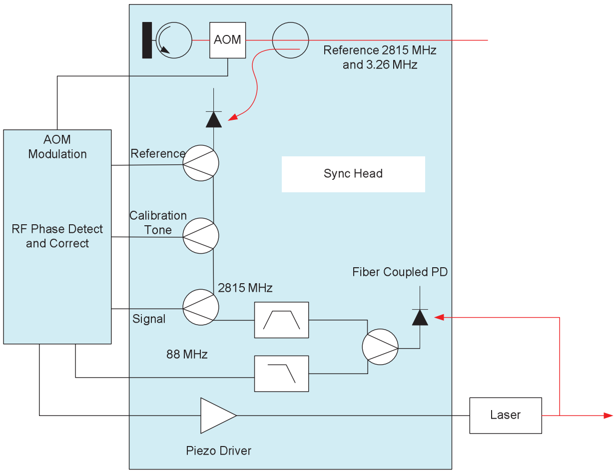

Figure 3: Laser oscillator stabilization.

FEEDBACK

The APS typically runs user beam for six continuous days. Beam-based feedback will be used to maintain stable operation over this period. Phase errors in either the upstream or downstream SPX deflecting cavities will cause an orbit shift. This orbit shift will be detected by the BPM system. Conceptually, the SPX deflecting cavities will be treated as additional correctors for orbit control, and feedback can be applied to cavity phases to correct for long-term drifts.

The storage ring beam-arrival time at the upstream SPX sector varies with undulator gaps. For all gaps open to close, the variation can be as much as 64 degrees of phase [4]. For normal operation, the variation due to users opening and closing gaps randomly is approximately +/- 6 degrees.

A beam arrival time (BAT) monitor is planned for SPX. It will be used to feedback to the storage ring main LLRF to correct for beam arrival time shifts. It will be positioned just upstream of the SPX zone. At this point the BAT will not be specified for stable operation down to DC. However, as planned, it will be able to compensate for beam arrival time shifts due to normal ID gap opening and closing. It will not, however, be stable enough to correct for long-term drifts in beam arrival time.

A shift in beam arrival time at the upstream cavity will appear as a common mode phase error and be manifested as a transverse orbit shift by the BPM system. Feedback from orbit control to the upstream deflecting cavities will cause the cavity phases to track the beam arrival time drifts. The resulting cavity phase will be fed forward to the laser link stabilizers via the control system and cause the laser oscillators to track this slow drift.

CONCLUSION

The SPX project imposes demanding tolerances on deflecting cavity phase and laser oscillator synchronization. The collaboration with LBNL will result in implementation of a timing/synchronization system capable of achieving these tolerances.

REFERENCES

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