TEST RESULTS OF THE LIBERA SYNC 3 CW REFERENCE CLOCK TRANSFER SYSTEM

P. Orel, E. Janezic, P. Lemut, S. Zorzut, Instrumentation Technologies, Solkan, Slovenia
S.G. Hunziker, V. Schlott Paul Scherrer Institute, Villigen, Switzerland

Abstract

The new Libera Sync 3 CW reference clock transfer system has been specifically designed to meet the strict requirements of the latest fourth generation light sources, such as the Swiss FEL. The system has been co-developed with the Paul Scherrer Institute (PSI). It has been produced and tested at Instrumentation Technologies (I-Tech) and later installed at PSI. In this article we give a general overview of the system and its functionalities. Furthermore we present a brief overview of the supporting products that have been developed in order to enable testing at the discussed level of performance. Finally we focus on presenting some of the test results obtained at I-Tech and PSI which show the performance capabilities and limitations of the system.

INTRODUCTION

Free Electron Lasers (FEL) require high performance synchronization throughout the entire machine. An extremely important element of this synchronization is the reference clock transfer system.

Typical requirements in terms of added jitter and long-term phase stability are below 10 fs for jitter and below 40 fs for phase stability per day [1].

Our approach is based on a continuous wave (CW) modulation of an optical carrier in which phase detection and stabilization are done in the radio frequency (RF) domain [2].

SYSTEM OVERVIEW

Figure 1: Libera Sync 3 Unit pair.

Figure 1 above shows a unit pair of the Libera Sync 3. The system is composed of a transmitter and a receiver units connected by two optical fiber links [3].

The two fiber link is used in order to overcome optical limitations, mainly due to the Rayleigh backscattering effect [4]. One fiber is used for the transfer of a low-noise signal while the second is used for the transfer of a low-drift reference signal. This combination yields ultra-low added jitter and low drift.

The system control architecture is based on two separate micro-processing units, where one is solely dedicated to the low-level control and monitoring of the link while the other manages the user interface and the high level diagnostics thus ensuring a robust and highly reliable operation.

The embedded low-level software features a state machine which is responsible for making the locking procedure completely automatic. Upon startup the state machine identifies, calculates and sets the optimal operating points for the link and starts the various regulation loops sequentially. The locking procedure takes up to 2 hours, after that a relaxation period of a couple of days is necessary in order for the system to fully stabilize.

The system on both low and high levels has an extensive diagnostic apparatus which monitors everything from link stability to the environmental conditions both inside and outside of the units. All of the parameters can be accessed on the local display or over the Ethernet interface.

RESULTS

Three unit pairs have been measured for both jitter and long-term phase stability. All three have been measured with the same setup elements which were comprised of a low phase-noise RF generator, long term stable phase detector, temperature compensated RF cables and temperature stabilized splitters. The environmental conditions of the setup in terms of temperature and humidity stability have been kept to within ±7 °C and ±6 % respectively. For the majority of the measurements the room was sealed so no artificial sources of vibrations were present.

Jitter performance

The residual phase noise has been measured at offset frequencies ranging from 10 Hz to 10 MHz. Making use of the differential method [5] the residual phase noise was down-converted into the baseband which was then sampled by the Agilent E5052B signal source analyzer. Matlab was used for further jitter integration and estimation. Figure 2 shows a block diagram of the setup used.

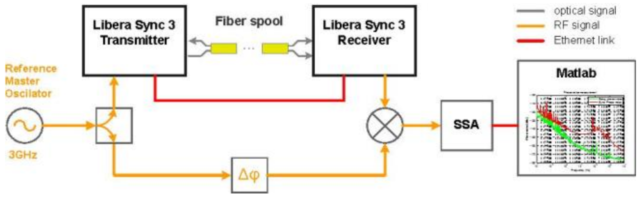

Figure 2: Jitter measurement setup.

Figures 3 and 4 show the residual phase noise and added jitter of the three Libera Sync 3 unit pairs respectively.

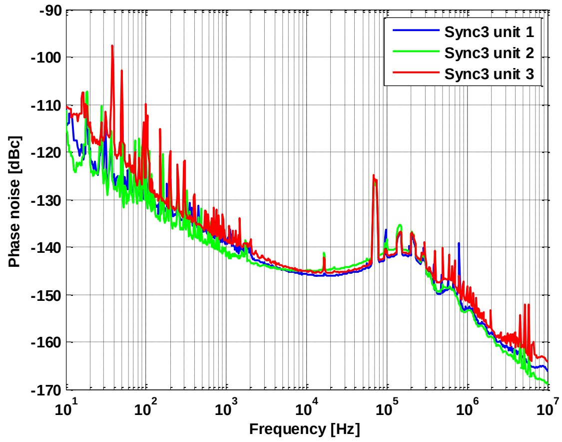

Figure 3: Residual Phase noise.

The bump at offset frequency 1 MHz is an effect which is essentially a drawback of the differential method where the correlated noise of both paths does not cancel out. This happens due to a very narrow filter in the receiver unit which filters out the correlated noise of the Device under test (DUT) path, causing the correlated noise to leak into the baseband signal, consequently adding to the DUT residual phase noise. The spurs at low frequencies are attributed to mechanical vibrations and to the coupling of the 50 Hz power line component.

The spurs at higher frequencies are attributed to the local power supply circuit. The spur at 68 kHz is present in the measurement instrument.

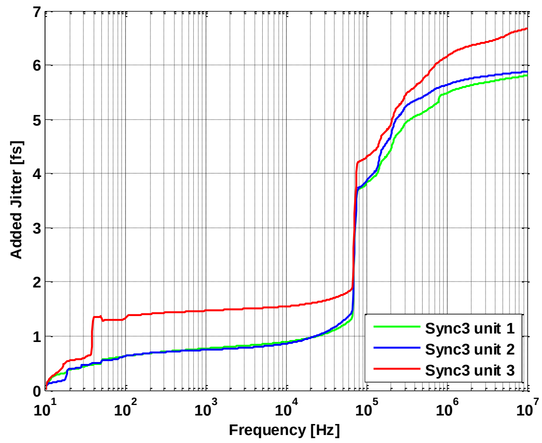

Figure 4: Added Jitter.

In Figure 4 we see the integration of the residual phase noise into jitter. It clearly shows how the bump at around 1 MHz is the most significant contributor to the overall jitter estimation.

The mean jitter performance of all three pairs is estimated to be around 6.12 fs with the measurement uncertainty on the order of ±0.5 fs. However due to the strong contribution from the bump we estimate that the real jitter performance is below 6.12 fs.

Long-term phase stability

The long-term phase stability was measured using a specially designed, temperature stabilized phase detector which compared the DUT path to the reference path (passive). The drift of the setup itself is estimated to be on the order of a few femtoseconds peak-to-peak per 24 hours. Figure 5 shows the block diagram of the measurement setup.

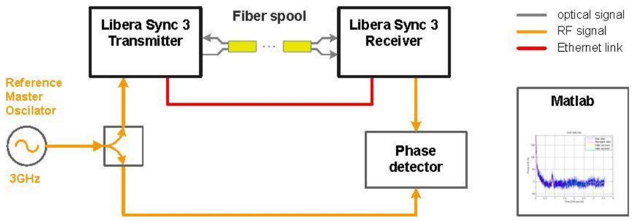

Figure 5: Phase drift measurement setup.

Figure 6 shows a plot of the normalized phase drift of one of the unit pairs.

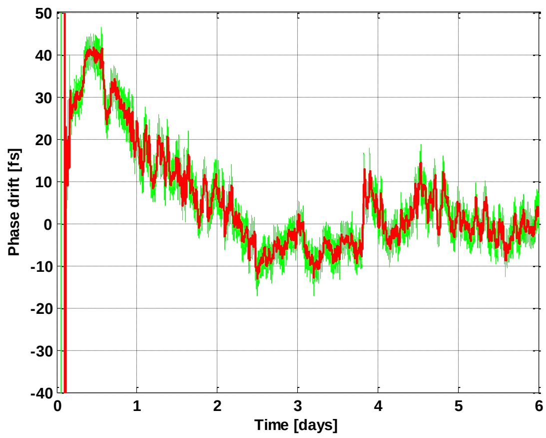

Figure 6: Normalized Phase drift.

As mentioned above a unit pair requires a couple of days of relaxation in order to properly stabilize which is clearly seen in the Figure 6 above. The curve in green shows raw data while the red curve uses a smoothing algorithm to attenuate the detector noise and show the drift performance more clearly. Sampling time was approximately 2.16 s.

The following analysis takes into account approximately 16 days of data from all three unit pairs. Distinctions in performance from one unit pair to another are present but are not significant.

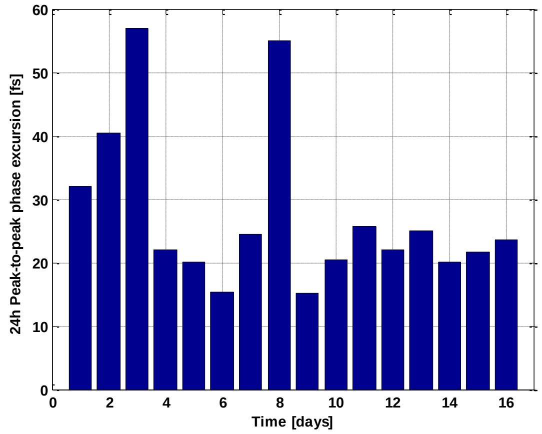

Figure 7: 24h p-p phase drift.

Figure 7 shows maximum peak-to-peak phase drift excursions within a 24 hour period.

Figure 8 shows the RMS value of the phase drift excursions within a 24 hour period.

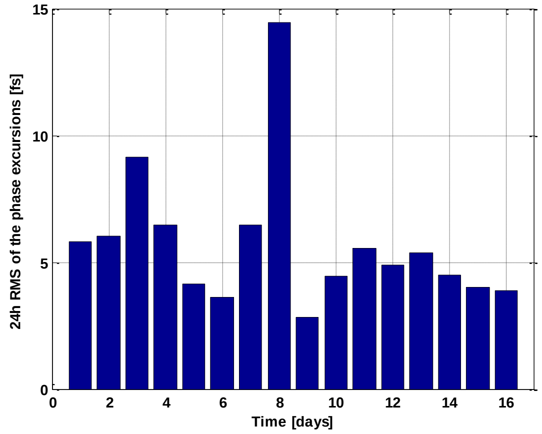

Figure 8: 24h RMS phase drift.

The worst case peak-to-peak phase drift excursion is around 57 fs. The overall mean value of the peak-to-peak phase drift excursions within a 24 hour period is around 27.5 fs with a standard deviation of 5.72 fs.

Measurement equipment

Within the project scope we developed a special equipment in order to measure the jitter and drift on the femto-second scale. Three such instruments are worth mentioning: a RF generator, a Phase detector and a general purpose temperature stabilizing unit.

The RF generator is built for single frequency operation where its performance is defined by an ultra-low noise temperature stabilized quartz oscillator and a low noise RF chain which yields an output signal of +21 dBm with an integrated jitter of less than 20 fs in the frequency range from 10 Hz to 10 MHz.

The detector unit is based on the Analog Devices AD8302 IC. Its stability is enhanced by having the board temperature stabilized to within 1 m°C and by having a very low noise power supply. When thermally stabilized and driven with proper RF power levels, the AD8302 IC exhibits minimal phase drift in the range of few femto-second per day.

The general purpose stabilizing unit is a circuit which can be attached to any block and perform temperature stabilization. Its stability is within 1 m°C and has a settable temperature set-point and range. This unit was used to stabilize all passive setup components as well as other passive and active prototype block used during testing.

CONCLUSION

The new Libera Sync 3 transfer system integrates a novel approach with state-of-the-art technologies, ultimately providing outstanding performance, high reliability and reproducibility as well as ease of use.

The results show that the system is mature and ready for production. The current units run on 2998.8 MHz frequency but can be easily adjusted for other frequencies. The next step is the adjustment for the center frequency of 2856 MHz, which will also be installed at PSI.

REFERENCES

[1] V. Schlott et al., “Reference distribution system for SwissFEL”, Libera Workshop (2012)

[2] M. Vidmar et al., “Chasing Femtoseconds – How accelerators can benefit from economies of scale in other industries”, IPAC (2011)

[3] P.Orel, S. Zorzut et al.,“Next generation cw reference clock transfer system with femtosecond stability”, NAPAC (2013)

[4] T.H. Wood, R.A, Linke, B.L. Kasper, and E.C. Carr, “Observation of coherent Rayleigh noise in single-source bidirectional optical fiber systems,” *J. Lightwave Technol.*, vol. 6, no. 2, pp. 346-352, Feb. 1988.

[5] R. Boudot, E. Rubiola, “Phase noise RF and microwave amplifiers”, FEMTO-ST Institute (January 2012).