TOWARDS AN ULTRA-STABLE REFERENCE DISTRIBUTION FOR THE NEW PSI 250 MeV INJECTOR

S. Hunziker#, V. Schlott, Paul Scherrer Institut, CH-5232 Villigen, Switzerland

Abstract

The PSI 250 MeV Injector, a precursor to the SwissFEL, with its extreme jitter and stability demands poses new challenges for the synchronization system. Our concept is double-tracked: low risk electrical and best potential performance and flexibility optical. The electrical distribution system, being established first, relies on reliable technology. Optimized to achieve a benchmark jitter performance of around 10 fs and a long term drift stability of some 10 fs in the most critical parts of the machine it will also backup the optical system. Sub 10 fs jitter and drift figures are being aspired for the latter. In this contribution, both system designs are presented, expected and first measured electrical and optical reference signal jitter and long term cable and coupler drifts are presented. A cable temperature stabilization system is discussed, too. Finally, a first jitter measurement of the optical master oscillator (OMO) laser will be presented.

INTRODUCTION

The 250 MeV Injector will be ≈65 m long and basically consist of an electron gun (with photocathode), S-band structures, an X-band structure and a bunch compressor as depicted in Fig. 1. These structures are driven by RF signals, which are synchronized to the distributed reference signal. Other “customers” of the reference distribution system are e.g. photocathode laser, timing system, diagnostics in general. The building is ready, first installations are being done now (Spring 2009). The reference distribution is one of the key challenges. Extremely tight timing jitter requirements demand for solutions on the edge of technical feasibility. On the other hand cost and reliability issues have to be considered. Both distribution concepts, the electrical and the optical one, are sketched in Fig. 2.

ELECTRICAL REFERENCE DISTRIBUTION

Architecture

The coaxial cable based baseline system consists of:

- Low phase-noise 214.14 MHz RF master oscillator (RF MO), will be ready by June 2009.
- RF power amplifier (P_{out}>37 dBm) providing required signal levels at the terminals (points where the reference signal is needed) reference inputs.
- Directional couplers, feeding and decoupling reference inputs of the various terminals, e.g. PLO (=phase locked oscillator for 1.5, 3.0 and 12 GHz) reference inputs, located along a trunk line.

Active subsystems are supplied with ultra-low noise linear power supplies.

Drift, Temperature Stabilization, RF MO

Multiple coaxial cables form the trunk line within the accelerator tunnel (depicted in red in Fig. 2). They are guided within a thermally isolated pipe, which is supplied with a temperature controlled heater cable (Fig. 3). The pipe is supported with hard foam plates on cable trays and periodically furnished with temperature sensors. Various cables (basically 3/8” and 7/8” coax, which are relatively inexpensive) are installed in parallel, offering the possibility to find the one with lowest drift after installation by optimizing the temperature within the pipe. It has been found that the temperature stability as well as the optimum operating temperature for minimum drift of low loss corrugated coaxial cables may strongly vary from production lot to production lot, which requires flexibility and redundancy during installation.

The measured temperature stability of various cables is listed in Table 1.

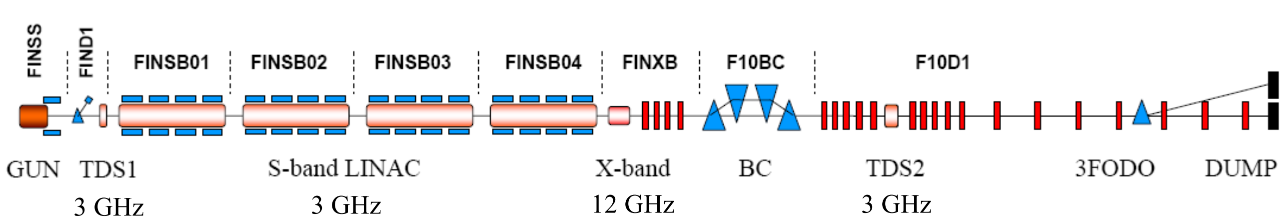

Figure 1: Simplified layout drawing of the PSI 250 MeV Injector [1].

#stephan.hunziker@psi.ch

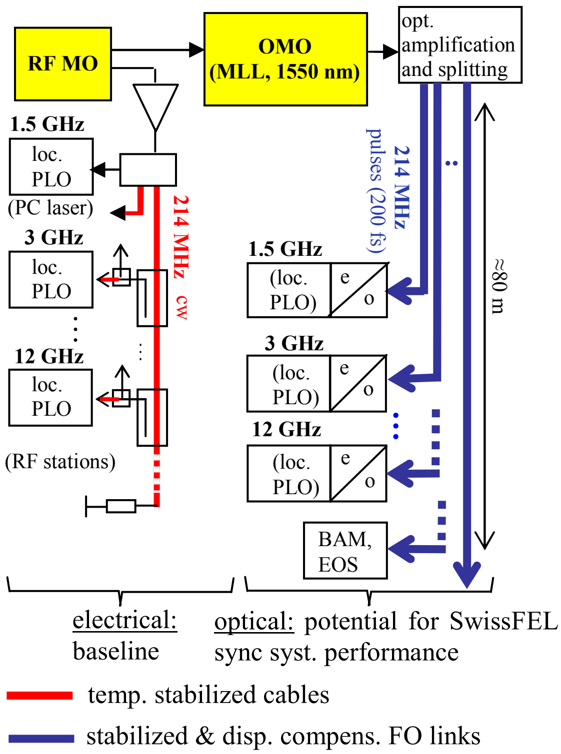

Figure 2: Simplified layout of electrical and optical reference distributions for the PSI 250 MeV Injector.

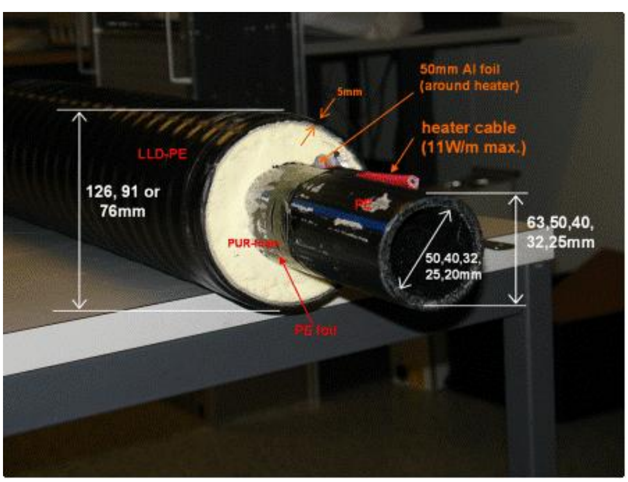

Figure 3: Temperature controlled cable pipe.

Corrugated low loss cables are the preferred choice for the trunk line, whereas flexible braided cables are used where small bending radii are required (e.g. within racks or to connect couplers and splitters). The temperature drift for the 7/8" cable seems to be quite high. The measured cables are obviously from a non-optimum production lot, whereas the 3/8" shows low drift, even though at higher than expected temperature. Typically the 7/8" Cellflex and the 3/8" Heliax (both temperature cycled at the manufacturer's site to minimize drift and relaxation effects) are expected to show approximately zero drift at ≈33 °C (7/8") and at 27..30 °C (3/8") respectively [2].

Expected drifts of the electrical system (in the critical front part of the machine over hours) are thus:

- 30 m of Heliax 3/8" (<0.2 °C stab.) <15 fs drift
- some m of Sucoflex 404 (<0.2 °C stab.) <10 fs drift
- directional coupler: ≈3 fs/°C drift
- total: <50 fs drift achievable

Specified and expected jitter values for the RF MO and the PLOs are shown in Table 2. The phase detectors inside the PLOs are extremely critical w.r.t. drift and therefore a weak point. They will be temperature stabilized to minimize drift between the RF stations' reference signals.

Table 1: Measured Coaxial Cable Drifts

Cable type	Temp. [°C]	Drift [ppm/K]	Drift [fs/m/K]
Andrew Heliax 3/8" corrugated (low loss, low drift) $IL_{214\ MHz}$=5.5 dB/100 m	28.0	-2.9	-10.9
	30.0	-2.2	-8.1
	32.0	-1.5	-5.6
	34.0	-1.2	-4.6
	36.0	-0.3	-1.0
	38.0	+0.1	+0.5
RFS Cellflex 7/8", corrugated (very low loss) $IL_{214\ MHz}$=1.8 dB/100 m	27.5	-6.4	-23.6
	29.5	-6.7	-24.8
	31.5	-8.1	-30.0
	33.5	-6.4	-23.7
	35.5	-5.0	-18.3
	37.5	-5.4	-19.8
Huber+Suhner Sucoflex 404, braided (flexible, low drift) $IL_{214\ MHz}$=0.1 dB/m	26.0	-1.1	-4.2
	28.0	0.0	0.0
	30.0	-0.4	-1.4
	32.0	-5.3	-19.8

Table 2: RF MO and PLO Jitter Specifications and Expectations

Jitter (guar., typ.)	Δf=1 kHz..10 MHz, f_0=3 GHz	Δf=10 Hz..10 kHz, f_0=214.14 MHz
RF MO	-	13.0/9.5 fs
PLO, locked to MO	11.3/6.7 fs	-
specified	<10 fs	<20 fs

Figure 4 shows the block diagram of the RF MO. A Rb standard stabilizes the frequency (no long term phase differences between terminals due to ref. frequency drift). The close-in phase noise is optimized using two 10 MHz OCXOs (oven controlled x-tal oscillators) which are multiplied by 5 and mixed rather than doubling one oscillator's frequency, halving jitter (same for the 107.07 MHz oscillators). A 100 MHz frequency ref. unit, optimized for the medium offset frequency range, is locked to the 1st stage. A DDS (direct digital synthesis) adapts 107.07 MHz to the 100 MHz. First measurements of single blocks suggest that the typ. rather than the guaranteed jitter values will be reached.

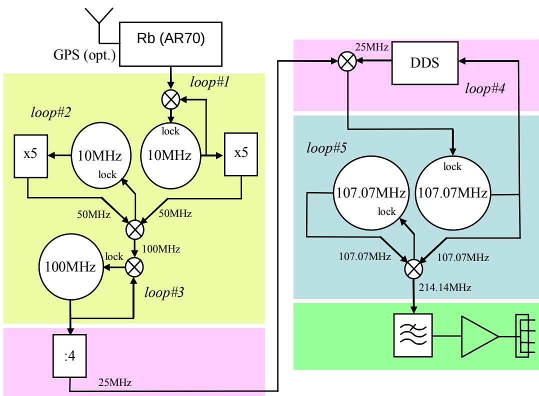

Figure 4: Block diagram of the RF master oscillator (214.14 MHz) [3].

OPTICAL REFERENCE DISTRIBUTION

Architecture, Link Stabilization

A star network (Fig. 2) of standard SM optical fiber bundles with plenty of redundant fibers offers high flexibility as every terminal in the facility can be patched with every other terminal at the OMO patch panel. Furthermore, many links will have to be compensated using DCF fibers, known from telecom applications [4] and phase stabilized as previously demonstrated for fs pulse transmission [5]. Link stabilization using optical cross-correlation is planned. Reliability-critical free-space delay lines used in these systems up to now may have to be replaced with more reliable components (e.g. in a combination of slow and fast delay correction). A commercial solution would be favored, the more so as e.g. Menlo Systems (www.menlosystems.com) is currently developing a link stabilization system as well as a Sagnac-loop based PLL. Temperature-stable LCP coated fibers [6] could be an alternative to active stabilization, at least for less critical links. The optical system is planned to be operational within the next two years

Optical Master Oscillator (OMO)

Basically, two OMO laser types are currently under evaluation, an Yb-doped hybrid (fiber, solid-state) femtosecond laser and a fiber laser. Both lasers are nearly transform limited soliton lasers (allows fiber-based dispersion compensation). Lowest jitter and highest stability up to now have been achieved with the former. Figure 5 shows the typical result of a phase noise and jitter measurement of the Onefive Origami 15 laser (1550 nm wavelength, 214.14 MHz rep. rate) [7]. This laser has an average optical output power of >120 mW (free space) or >70 mW (fiber coupled). For the measurement an Agilent E5052B SSA has been used. The influence of the setup noise has been minimized using SSA noise cancellation (10'000 correlations), a waveguide PD operated at max. V_{bias} (high saturation limit) and high photocurrent (≈2.5 mA), high carrier frequency, linear power supplies with additional filtering.

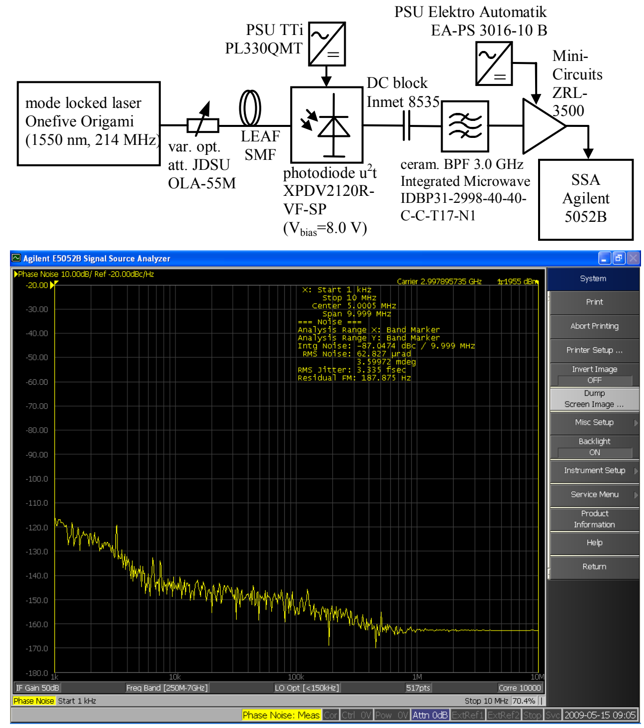

Figure 5: Measured phase noise of Onefive Origami 15 Soliton laser (Δf=1 kHz..10 MHz, f_0=2.998 GHz=14th harmonic of rep. rate 214.14 MHz): Setup (top), phase noise spectrum, timing jitter of 3.3 fs (bottom).

PLOs

Generating ultra-low jitter synchronisation signals by extracting harmonics from the optical reference pulses is feasible, using optimized optical receivers (Fig. 5). As a next step, the drift performance of such receivers is being investigated and optimized. It has been shown by other groups that ultimate low drift (some fs) PLOs can be realized using optical-to-electrical phase detectors (Sagnac-loop PLL) [8]. As these PLOs are rather expensive, their use can be limited to situations where ultimate performance is really required. In other cases, direct harmonic extraction seems to be sufficient.

REFERENCES

[1] http://fel.web.psi.ch/
[2] http://www.wancom.com.cn/efiles/440-635.pdf http://www.rfsworld.com/userfiles/pdf/Transmission_Line_Tech_Section.pdf
[3] http://www.inwave-gmbh.de
[4] R. Wilcox et al., "Fermi Timing and Synchronization System", Lawrence Berkeley Natl. Lab. LBNL-61165, 2006. repositories.cdlib.org/lbnl/LBNL-61165
[5] J. Kim et al., Opt. Lett. 32 (2007) 1044.
[6] T. Kakuta and S. Tanaka, Int. Wire & Cable Symp. Proc., p. 234 (1987).
[7] http://www.onefive.com
[8] J. Kim et al., Nature Photonics 2 (2008) 733.