FERMI@ELETTRA TIMING SYSTEM: DESIGN AND RECENT SYNCHRONIZATION ACHIEVEMENTS

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Abstract

FERMI@elettra is the fourth generation light source under construction at Sincrotrone Trieste. Being a seeded-FEL source, the requirements for the timing system are very tight as the final goal is a stable seeding process with sub-picosecond electron bunches and seeding laser pulses. Based on demonstrated results achieved in the main laboratories worldwide active in the field, like DESY, LBNL and MIT, an hybrid timing system scheme has been proposed which is currently under development. Both "pulsed" and "continuous wave (CW)" optical timing systems are being deployed, the choice being based on the differences among the different timing system clients; a Low Level Radio Frequency processor is a "quasi-CW" client whereas the lasers and some "longitudinal" diagnostics are "time discrete" clients. In this paper the FERMI@elettra timing system and the recent advances are presented. A pulsed optical clock has been locked to an ultra stable reference; its output pulses distributed over stabilized fiber optic links. As a benchmark client, a femto-second laser oscillator has been synchronized to the optical clock testing different possible schemes.

OVERVIEW OF THE FERMI TIMING SYSTEM

The FERMI timing and synchronization (T&S) scheme (see figure 1) is based on a hybrid system utilising both “pulsed” and continuous wave (CW) optical timing techniques. The optical “pulsed” technique has been originally developed at MIT [1], whereas the “CW” optical technique by LBNL at Berkeley [2].

Timing system clients

The optical pulses distributed over dispersion compensated fiber links (FO) give the time reference to all the “pulsed” timing clients, such as lasers and diagnostics systems. The “CW” optical timing, developed by LBNL at Berkeley, is based on a frequency stabilized CW laser, amplitude modulated by the radio frequency (RF) needed as a phase reference by the timing clients, such as low level RF systems. In this scheme, the FO links are stabilized using the optical mixing concept which fully exploits the ratio (10^5) between the optical carrier frequency and the RF signal to be distributed. The reference oscillator for the whole timing system is a microwave sinusoidal oscillator [3], operating at the European X-band frequency of 11.992GHZ, which provides the required, fs grade, ultra low phase noise and long term stability. The oscillator is housed in a temperature controlled “timing hutch” close to a set of ultra low phase noise dividers which generate the European S-band frequency (2,998.010MHz), the optical master oscillator (OMO) reference frequency, $f_{REF\ OMO}$), and the greatest common divisor frequency, f_{COIN}, output signals. The output signals are distributed to the OMO, to the CW timing and to the master time-base unit and finally, via dedicated stabilized optical channels, to the timing system end users.

The timing system is completely integrated into the FERMI control system, thus allowing for remote control and monitoring of the performance and reliability of all key sub-systems.

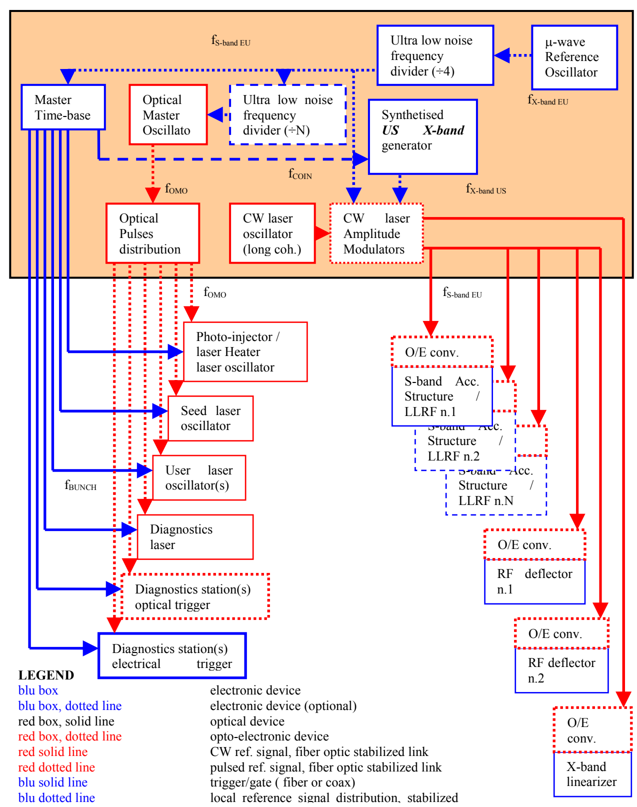

Figure 1: Block diagram of the FERMI timing system.

TIMING SYSTEM SPECIFICATIONS

The various timing system clients have different requirements in terms of maximum allowed jitter. These values have been computed by means of jitter sensitivities studies carried out for the FERMI accelerator [4].

Jitter budget

For each timing client, the net effect on the jitter of the bunch is computed as the quadratic sum of the timing line (phase reference) and the client (sub-system) contributions, since the two contributions are Gaussian and statistically independent. The resulting values for each timing reference line are listed in table 1, under the heading "Timing line jitter".

Table 1: Allowed jitter for each timing line.

Timing client	Client jitter [fs_{RMS}]	Timing line jitter [fs_{RMS}]	Bandwidth of interest
RF S-band	167	118	DC - 1kHz
RF X-band	69	49	DC - 1kHz
Photo-injector laser	200	141	DC - ≈1kHz*
seed laser	100	71	DC - ≈1kHz*
experimental laser	100	71	DC - ≈1kHz*
Streak Camera driver	500	354	DC - 1kHz
Streak Camera fiducial	100	71	DC - 50MHz
Bunch arrival monitor	100	71	DC - 50MHz
EO sampling station	100	71	DC - 50MHz

* synchronized by means of electrical timing stabilizer

In Table 1, under "Bandwidth of interest", the bandwidth within which each timing client is most sensitive to jitter has been indicated. The different sensitivities are explained by the intrinsic band characteristics of the sub-systems (RF accelerating structures) and the related stabilization loops (laser PLLs). This is an important issue that must be taken into consideration in the design of the timing lines to the different sub-systems.

Reference frequencies for FERMI

The FERMI timing system has to be compatible with both the European ($f_{S\text{-band-EU}}$=2.998010GHz) and U.S ($f_{S\text{-band-US}}$=2.856GHz) S-band frequencies (see Table 2). This is a necessary condition since the fourth harmonic (X-band) linearizer, that is part of the FEL design, will work at the US frequency. The greatest common divisor of these two frequencies is the coincidence frequency f_{COIN} (15.779MHz) used to generate the "bunch clock" at the FEL repetition rate frequency f_{bunch} of 10-50Hz.

Table 2: Reference frequencies for FERMI

Signal name	Symbol	Value	Notes
μ-wave master	f_{MASTER}	11.992040GHz	EU X-band
FERMI RF	f_{RF}	2.998010GHz	EU S-band
US RF	$f_{US\ REF}$	2.855998GHz	US S-band
US X-band	$f_{US\ X\text{-band}}$	11.423996GHz	US X-band
G.C.D.	f_{COIN}	15.779000MHz	EU S-band/190 US S-band/181

The ultra low phase noise μ-wave master oscillator [3] will provide the fs level phase reference to the OMO and its S-band output will be directly distributed to the Radio Frequency clients by amplitude modulating the CW laser.

TEST SET-UP AT ELETTRA

The block diagram of the test set up for the Optical timing system at ELETTRA is shown in figure 2. The reference electrical (RF) generator is located in the Klystron Gallery of the LINAC, close to the Optical master Oscillator. An harmonically Mode Locked fiber laser [5] has been phase locked to the RF generator. The repetition rate of the optical pulses is 3GHz, the same of the RF generator. A 300m long single mode fiber stabilized link, indicated in red, distributes the Optical reference signal to the Storage Ring where the timing clients are located. Different schemes for the locking of remote clients are shown in figure 2, both electrical and optical.

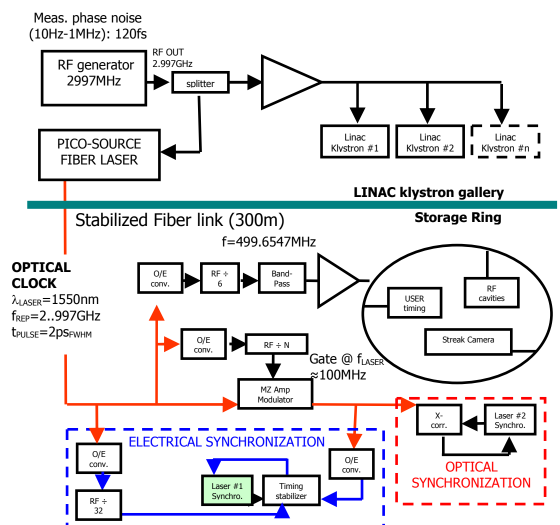

Figure 2: Optical Clock test bed at Elettra: red lines indicate optical signals, blu lines indicate electrical signals.

Extraction to an electrical timing reference

As shown in figure 2, to obtain an electrical timing signal from the optical reference pulse train at a remote station direct conversion to the electrical domain may be applied, followed by a division chain to obtain the required reference frequency to feed the timing stabilizer of the remote system (laser). In figure 3, the block diagram of the tested set-up is presented.

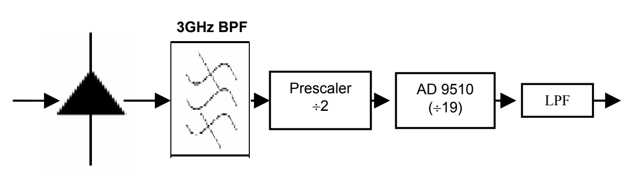

Figure 3: block diagram of the "direct conversion".

The optical pulses, generated by the stabilized harmonic Mode Locked fiber laser [5], are sent along an optical fiber link, laid down in the Klystron Gallery, with a length of 210m. The phase noise measurements have been performed using an Agilent 5052A Signal Source Analyzer (SSA) and are represented in figures 4a and 4b.

In figure 4a the phase noise of the electrical signal is reported, out of the Band Pass Filter downstream the photodiode. In figure 4b the phase noise of the low frequency reference after the dividers is shown. It's important to note that the SSB phase noise profiles can't be compared directly, as they refer to different carriers.

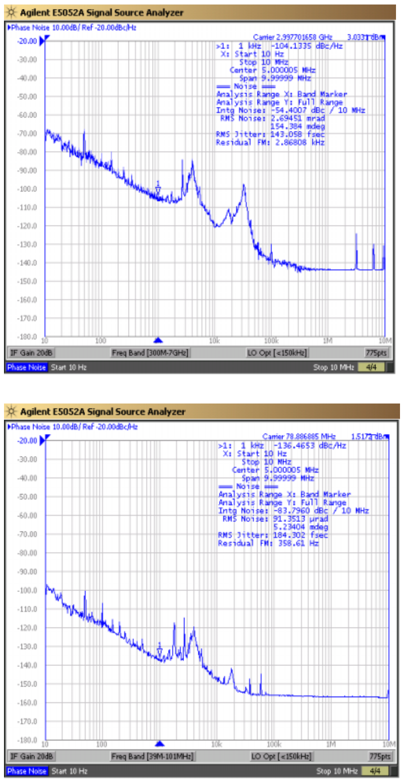

Figure 4: phase noise in the bandwidth 10Hz-10MHz of the extracted 3GHz reference, 143fs$_{RMS}$ (upper trace) and of the low frequency (78.86MHz) reference: 184fs$_{RMS}$ (lower trace).

Preliminary tests of a remote fs-laser oscillator synchronization

Some tests for the synchronization of a remote fs laser oscillator have been carried out using an available Cr:Lisaf laser oscillator.

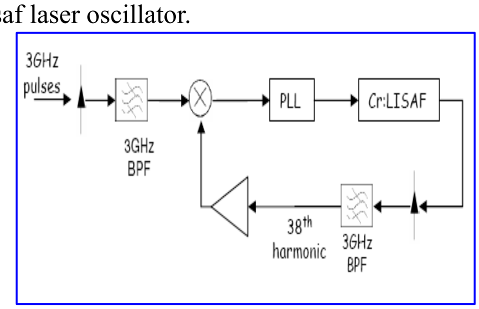

Figure 5: schematic of the remote laser synchronization to the 3GHz optical reference.

We installed standard telecom optical fibers (ITU-T G.652.A) and tested the links performance in terms of phase noise. After 210m of fiber optic link the timing jitter increases by about 15fs$_{RMS}$.

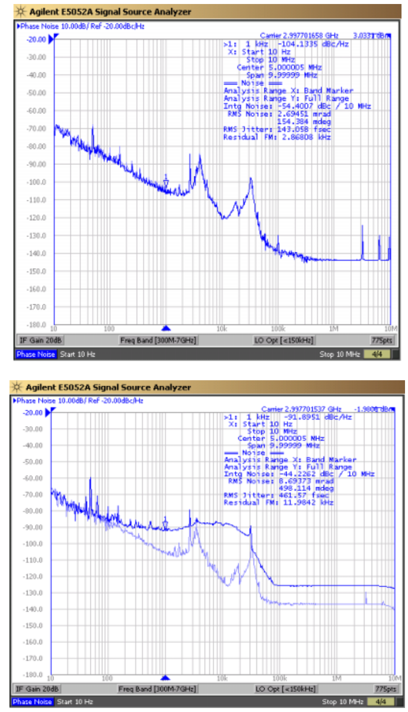

Figure 5, upper trace: phase noise of the Optical reference, 146fs$_{RMS}$. Lower trace: phase noise of the remote fs laser locked to it, 461fs$_{RMS}$.

By filtering an harmonic of the remote laser, it was possible to use this harmonic to lock the remote fs-laser with higher resolution. Tests need to be repeated in a quieter environment as remote laser set-up has not been optimized jet. The phase detection is performed at 3GHz, i.e. the 38th harmonic of the remote fs laser.

ACKNOWLEDGMENT

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