THE TIMBEL SYNCHRONIZATION BOARD FOR TIME RESOLVED EXPERIMENTS AT SYNCHROTRON SOLEIL

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Abstract

Time resolved experiments are one of the major services that synchrotrons can provide to scientists. The short, high frequency and regular flashes of synchrotron light are a fantastic tool to study the evolution of phenomena over time. To carry out time resolved experiments, beamlines need to synchronize their devices with these flashes of light with a jitter shorter than the pulse duration. For that purpose, Synchrotron SOLEIL has developed the TimBeL board fully interfaced to TANGO framework. This paper presents the main features required by time resolved experiments and how we achieved our goals with the TimBeL board.

INTRODUCTION

In synchrotron facilities, bunches of electrons turn inside a storage ring. Each time a bunch passes in front of a beamline, the beamline receives a flash of intense light. These light pulses are used by scientists to study phenomena evolving over time.

The short duration of the flashes allows the experiment scientist to freeze the current state of the sample. By analogy with photography, when the exposure time or the flash duration is too long, a moving subject will appear fuzzy on the picture (Figure 1). If the exposure time or the flash time is reduced, the subject appears clearly.

Figure 1: Fuzzy picture due to long exposure.

Thanks to the circular storage ring of a synchrotron facility, the light flashes occur continuously and at the revolution frequency. Using this stroboscopic effect, it is possible to study the evolution of a sample over a long period of time.

At Synchrotron SOLEIL, three main bunch filling patterns are dedicated to temporal studies: single bunch, eight bunch and hybrid modes (Figure 2). The associated flash frequencies are 847kHz for the single bunch and the hybrid modes, and 6.77MHz for the eight bunch mode. The flash duration is between 20ps to 40ps RMS. A low alpha mode to reduce this time down to 4ps will be proposed to users by the end of the year.

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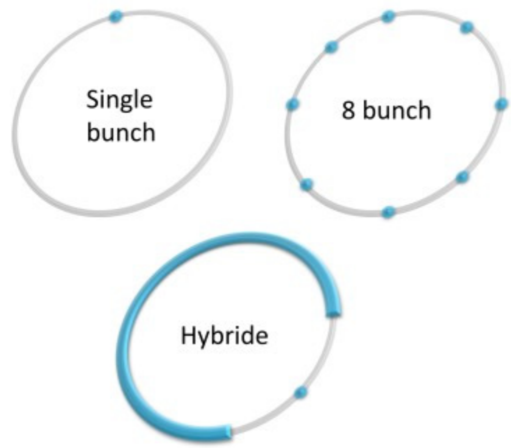


Figure 2: Hybrid, single and 8 bunch filling mode.

REQUIREMENTS

Synchrotron light flashes are not sufficient for scientists to perform time resolved experiments. They also need to synchronize their devices with bunches of electrons flying inside the storage ring, and delays must be added to compensate for cable and device time offsets (Figure 3).

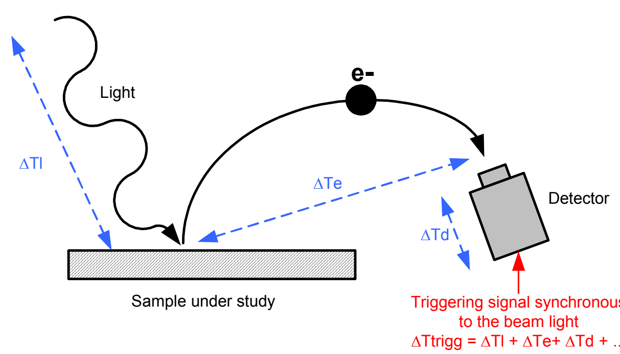


Figure 3: Delay offsets.

Because there are no dedicated pickup electrodes at Synchrotron SOLEIL, the synchronization triggers are generated from the radio frequency clock (352.196MHz). To guarantee synchronization with each bunch of electrons, the jitter of the system must be less than the bunch length (20ps RMS for the normal operating mode).

As a first step a survey was performed to determine the needs of ten beamlines. A requirement matrix was made based on these inputs. It led us to design a system with: two independent outputs. Each output should provide a frequency between 88MHz and 0.76Hz. Each output should be delayed by step of #10ps between 0 and 1.44µs. This is enough to cover the full revolution period of the storage ring (1.18µs). The high / low level ratio of the pulse should be adjustable by the user. Clock outputs should be automatically synchronized to the storage ring clock. This allows us to always have the same time offset with respect to the electron bunch each time the machine is filled with a temporal bunch filling pattern. All these features must be user configurable through the control system.

To fulfill the above requirements, we have developed the TimBeL (TIMing BEamLines) board.

THE TIMBEL BOARD

The TimBeL system is a compact PCI board. It is made of a mother with one daughter board (Figure 4). All functions are performed inside a FPGA (Field Programmable Gate Array) implemented on the mother board. A PLX Technology [1] chip is used to communicate with the compact PCI crate. To enable experiments to remain always synchronous with the same bunch of electrons, the storage ring clock (CLK_SR) and the radio frequency clock (CLK_RF) are provided by the machine to beamlines. These clocks are used inside the FPGA as main clocks for state machines.

Because the jitter is too large on the FPGA outputs, a daughter board with a jitter cleaner has been added to the system. This board also provides delay lines for compensating time offsets by 10ps steps.

This architecture is versatile. Both the mother board and the daughter board may be upgraded independently to improve performance or to meet new requirements. Considerable work has been done on the PCB (Printed Circuit Board) to ensure good signal quality and integrity on both boards.

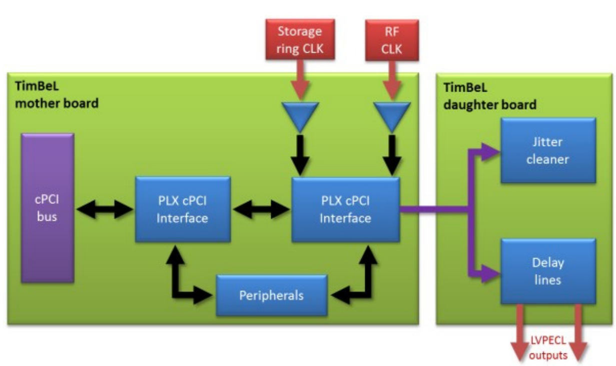


Figure 4: TimBeL architecture.

The mother board may also be used with other types of daughter boards for applications other than beamline synchronization.

A Tango device is used to configure the board outputs frequencies and time delays. This device accesses the FPGA's registers through a low level driver developed at Synchrotron SOLEIL (Figure 5).

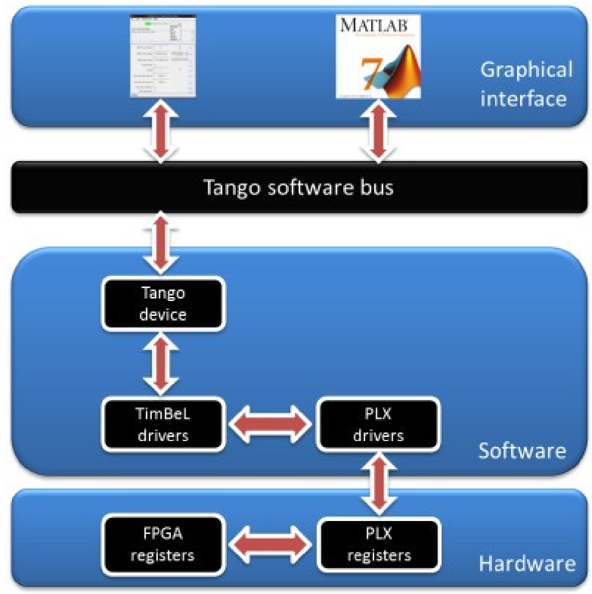


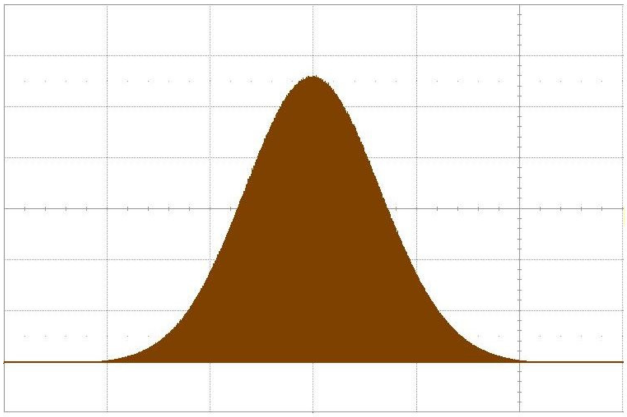
Figure 5: Software architecture.

Mechanical parts of the system have also been designed by Synchrotron SOLEIL. Manufacturing of the boards is however entrusted to an external subcontractor.

JITTER PERFORMANCE

The major concern with the performance of the board was jitter. To remain synchronous to the electrons bunches, the jitter must be lesser than 20ps RMS and we have totally achieved this goal.

The differential LVPECL outputs have a jitter of 3.3ps RMS @ 6.77MHz which is the 8 bunch frequency (Figure 6). In single ended mode, a LVPECL output has a jitter of 3.8ps RMS @ 6.77MHz. The source jitter (R&S signal generator [2]) is about 7ps RMS. All measurements have been made with a LECROY SDA 820Zi-A oscilloscope [3].



Jitter Kit	Period@level	Freq@level	Cycle to Cycle
mean	147.64257 ns		-2 fs
sdev	3.31 ps		5.73 ps
pkpk	29 ps		50 ps
max dev+	14 ps		23 ps
max dev-	-15 ps		-27 ps
max dev	15 ps		27 ps
num	101.493e+3		67.644e+3
status	✔		✔

Figure 6: TimBeL jitter.

Although it was not designed for this purpose, an Input / Output port on the board is also frequently used by beamlines as it directly provides a single ended LVTTL clock. On this I/O, the jitter is about 24ps RMS, measured with a TEKTRONIX TDS6640B oscilloscope [4].

SOME RESULTS

Each year, a few weeks are dedicated to time resolved experiments. In 2011, Synchrotron SOLEIL has provided its users with 2 single bunch and 2 eight bunch runs. Already 4 weeks of hybrid operation have been allocated and for the commissioning of the pump-probe lasers on TEMPO and CRISTAL beamlines this mode will be delivered until the end of the year.

Since 2009, a total of 6 beamlines have been using the TimBeL board either with their own devices or with the devices of their users. To date, all users have been satisfied by this board and its functionalities. No major complaints or problems have been reported.

Among other experiments, during last month, CRISTAL beamline has used this board to study photoinduced spin transition in molecular crystal [5]. The TimBeL was used to trigger a laser, a shutter, and an XPAD3.2 [6] synchronously with electron bunches inside the storage ring.

At the TEMPO beamline pump probe experiments were performed to directly observe the effect of Oersted fields in nanostripes during spin injection [7]. The TimBeL board is currently used for time resolved photoelectron spectroscopy experiments [8] and will be an essential element for planned experiments which will couple fs-laser pulses with the soft X-rays coming from the beamline.

The TimBeL board was also used successfully to test the pseudo single bunch mode under study at Synchrotron SOLEIL [9]. In this special hybrid mode, an isolated bunch of electrons is placed on a different closed orbit with respect to other bunches, using a fast pulsed corrector, active only for the isolated bunch. A TimBeL board was used on the machine to trigger the fast kicker magnet at a frequency of 1kHz. Another board was used on the TEMPO beamline to trigger the Scienta SES 2002 synchronously to this bunch. The first results obtained at the end of 2010 were very promising. This is an innovative and on-going in-house development.

CONCLUSION

A few years after the commissioning of the machine synchronization system [10], Synchrotron SOLEIL provided to beamlines the TimBeL board for time resolved experiments.

Unlike the machine timing system, the TimBeL board has been entirely designed by Synchrotron SOLEIL. This has helped us to modify and adapt it to experiments requests several times. Five firmware upgrades have been made since the board was installed on beamlines. Because we are perfectly familiar with this board, it was possible to adapt it very quickly, in just a few days, to new experimental needs and new data acquisition procedures.

The TimBeL board is a low cost and versatile system that has given satisfaction to beamlines for time resolved experiments.

REFERENCES

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[2] Rohde&Schwarz, SML01, 9kHz ... 1.3GHz.

[3] LeCroy, WaveMaster 8 Zi-A oscilloscope, 20GHz, 4x40GS/s.

[4] Tektronix, TDS6640B oscilloscope, 6GHz, 20GS/s.

[5] C. Laulhé et al., "Time-resolved pump-probe diffraction experiment at SOLEIL synchrotron: photoinduced spin transition in the molecular crystal [TPA Fe(III) TCC] PF6", PIPT4 2011.

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