THE TIMIQ SYSTEM FOR SUB-PICOSECONDS DELAY ADJUSTMENT

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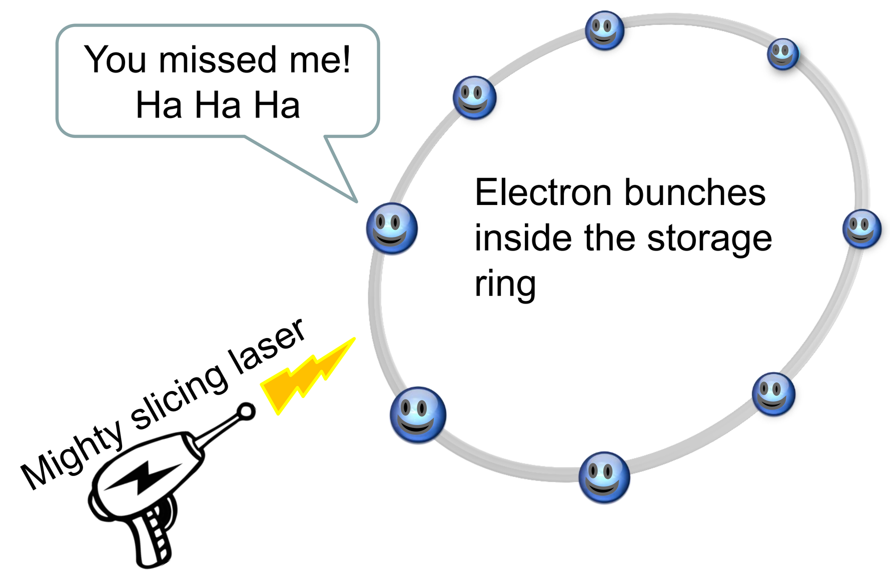
Introduction

In synchrotrons, bunches of electrons fly in a circular storage ring. Each time they pass in front of a beamline, they produce periodical flashes of light which are used for experiments.

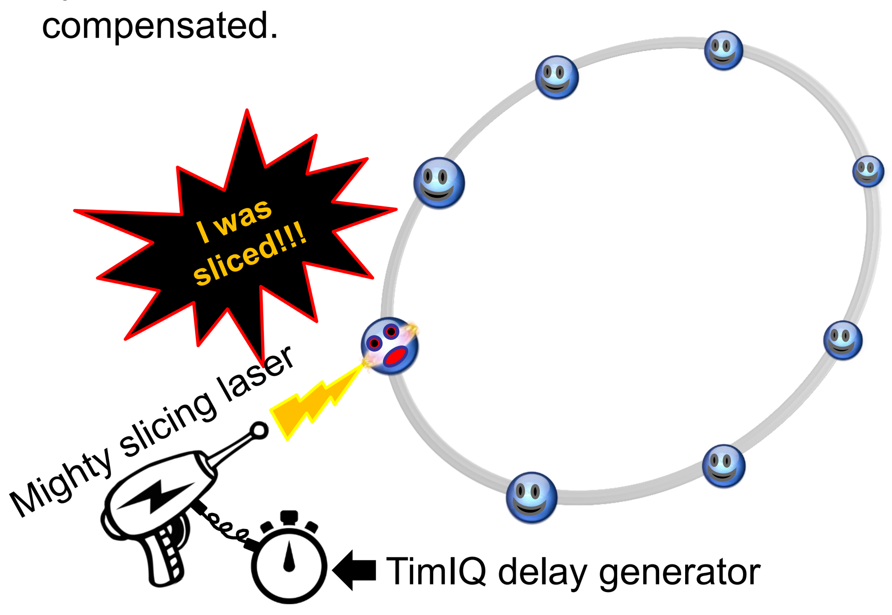
At Synchrotron SOLEIL, three filling modes are dedicated to time resolved experiments: single bunch, 8 bunches and hybrid mode. These modes produce very short (#40 ps – 80 ps FWHM) and very bright flashes of light. To study always faster phenomena, shorter x-ray pulses are required. SOLEIL provides low-alpha (#10 ps FWHM) and femtoslicing (< 1 ps) modes for this purpose.
At MAX IV the linac is built both for injecting the two storage rings as well as to provide short electron pulses for the Short Pulse Facility (SPF). At the SPF the electron pulses are sent through an undulator to provide 100 fs x-ray pulses to the FemtoMAX beamline.

Beamlines need a signal to synchronize their acquisitions with electron bunches inside the storage ring (SOLEIL) or inside the accelerator tunnel (MAX IV).
A typical application where a tight synchronization is required is the pump-probe measurement. A laser (pump) is used to stimulate a sample and the synchrotron light (probe) allows observing the evolution of the sample over time.
The laser and the detector must be synchronized with the electron and the time offset between devices needs to be perfectly adjusted.

During femtoslicing mode at SOLEIL, a laser interacts with a electron bunch. For beamlines using this mode, the resulting radiation is a sub-picosecond synchrotron light pulse.
This requires sub-picosecond delay adjustment between the laser and the bunch.



The laser's oscillator and the radio frequency cavities of the storage ring are driven by the radio frequency clock (RF) of the synchrotron. At SOLEIL the RF clock is at 352 MHz. Because the same clock is used for both laser and cavities, the electron bunch is naturally synchronized to the laser. But there is a time offset between them which must be compensated.



The TimIQ delay generator allows to do this compensation by phase shifting the RF clock of the laser's oscillator.

The TimIQ system is a joint development between SOLEIL and MAX IV.

The simple but so exciting principle of IQ modulation

A sine wave signal is represented as a circle in the Cartesian coordinate with an in-phase (I) and a quadrature (Q) component. Changing one of those component changes the phase (ϕ) and the amplitude (A) of the signal:

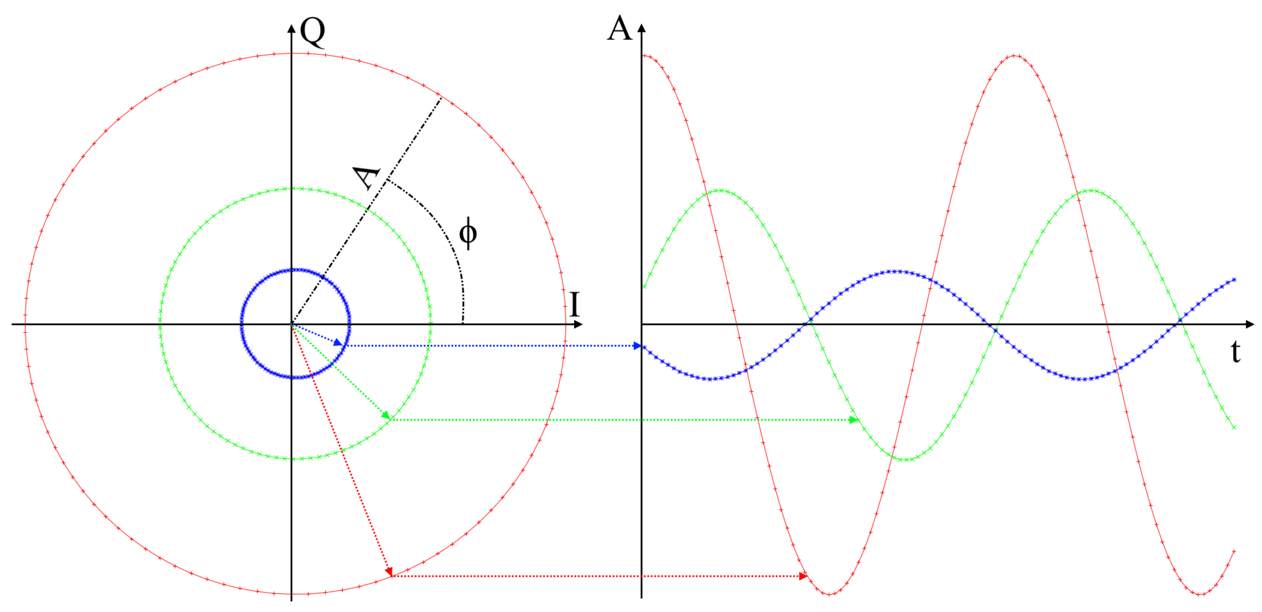
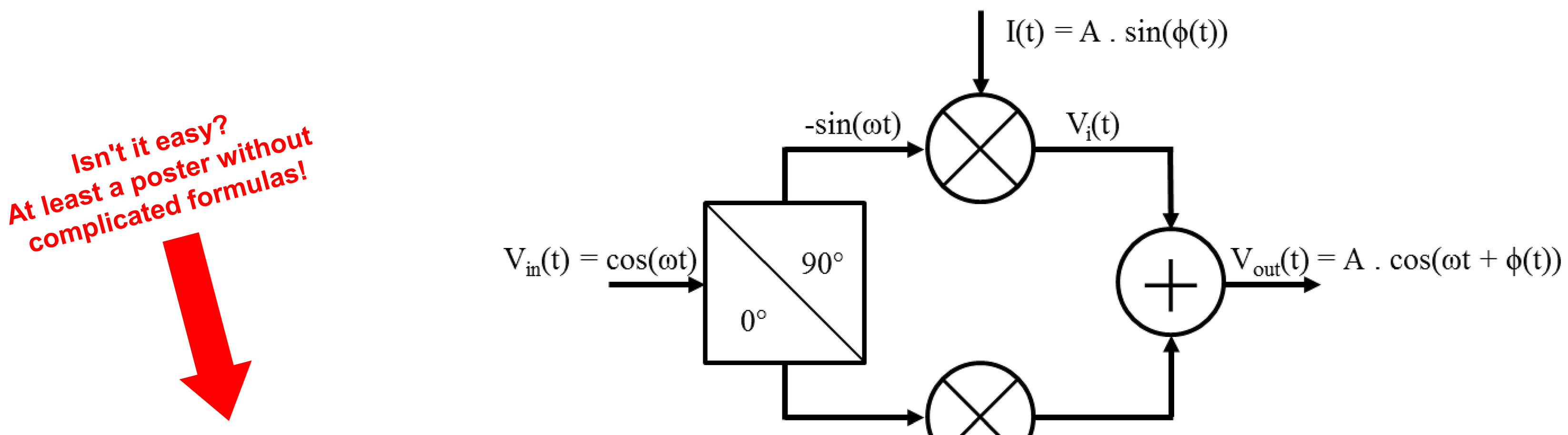


Figure 1: IQ modulation of a sine wave.

An IQ modulator device allows to adjust the phase and the amplitude of a radio frequency signal by modifying its I and Q components.
The input signal $V_{in}(t)$ is split in two branches. One of them is shifted by 90°. After multiplication by Q(t) and I(t), they are summed together to get the shifted output signal.



$V_{in}(t) = \cos(\omega t)$
$V_Q(t) = Q(t) . \cos(\omega t) = A . \cos(\phi(t)) . \cos(\omega t)$
$V_I(t) = I(t) . \cos(\omega t + \pi/2) = - A . \sin(\phi(t)) . \sin(\omega t)$
$V_{out}(t) = A . \cos(\phi(t)) . \cos(\omega t) - A . \sin(\phi(t)) . \sin(\omega t)$
$V_{out}(t) = A . \cos(\omega t + \phi(t))$

Figure 2: IQ modulator device schematic.

Forget the iPhone X and the Samsung Galaxy S8, here comes the wonderful the TimIQ 0

Soleil RF frequency is 352.196 MHz, whereas MAX IV RF frequency is 3 GHz. To make the system usable by both institutes, a PLL up-converts SOLEIL's RF clock to 2.8 GHz.
This signal is phase shifted by an IQ modulator which is controlled through an 18 bits Digital to Analog Convertor (DAC). The resulting signal is delivered to the laser oscillator either directly at 3 GHz for MAX IV or at 88 MHz after dividing the frequency by 32 for SOLEIL.
Two frequency mixers are used to measure the output to input phase shift. To improve the measurement's sensitivity, the input of one of the mixer is shifted by 90°. After filtering, they provide two voltages, $V_{0°}$ and $V_{90°}$, which gives the phase shift:

$V_{0°}(t) = B . \cos(\phi(t))$
$V_{90°}(t) = C . \cos(\phi(t) + \pi/2)$

By toggling the measurement from one mixer to the other, it is possible to readout the phase shift only on the linear part of the cosine function where the measurement is more accurate.
The mixers voltages are sampled with an 18 bits Analog to Digital Convertor (ADC). All components are managed with a FPGA. It transmits the data to an ARM microprocessor running a Linux operating system with an Apache web server.
The system can be controlled through Tango devices, python scripts or even with a simple web browser.

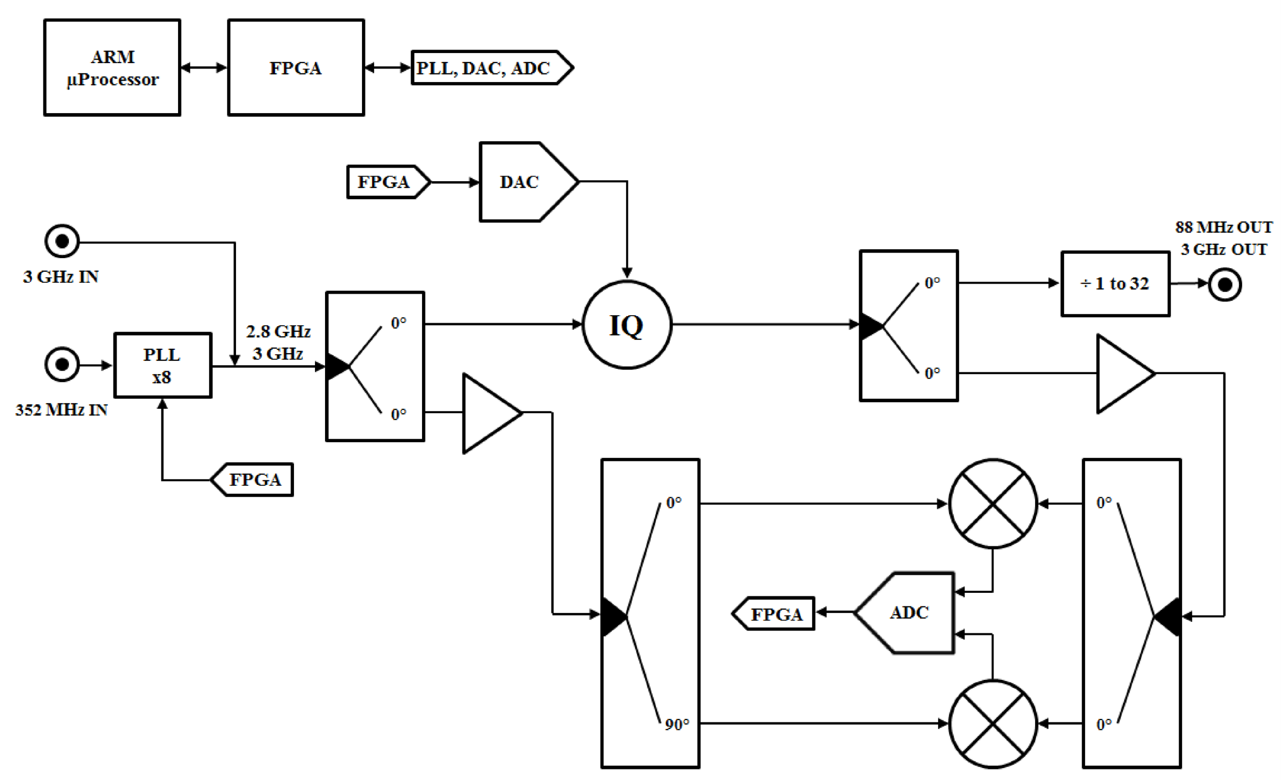


Figure 3: TimIQ architecture.

Resolution

The skew between the input and the output of the TimIQ system is measured by the two inboard mixers as explained above. When the output is delayed by steps of 40 fs, the readback from the mixer in its linear region where the resolution is the most accurate, is shown in the figure bellow.

The system is able to add delays down to **40 fs**.

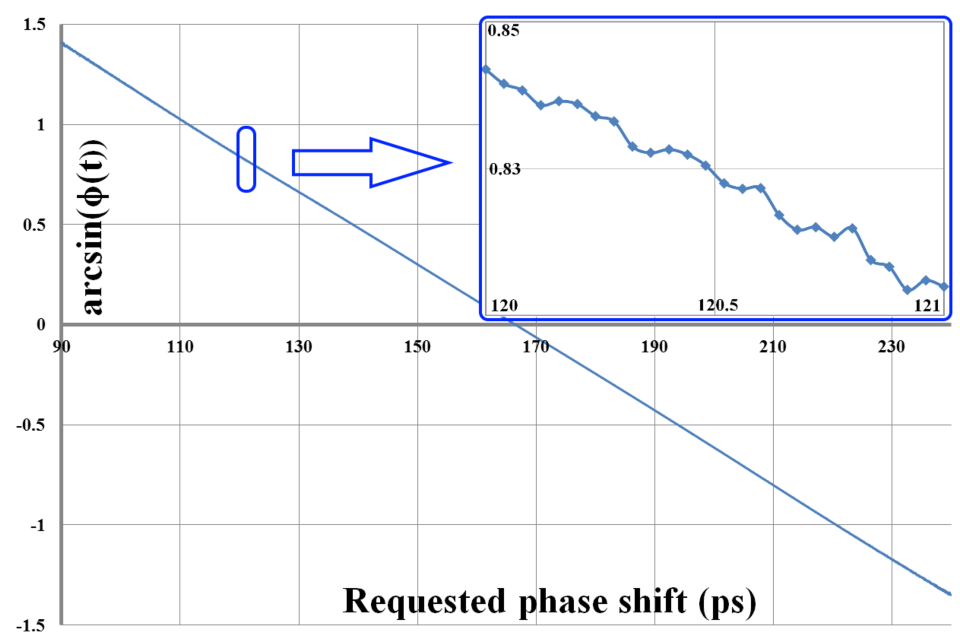


Figure 4: TimIQ resolution.

Precision and periodic error

The skew between the input and the output is measured with a Lecroy SDA 820 Zi-B, 20 GHz, 80 GS/s oscilloscope. The peak to peak difference between the measured and the requested phase shift is about **8.2 ps**. The **very good repeatability** of the traces allows to correct the error and to achieve a better precision by adjusting the I and the Q setting points according to this measurements.

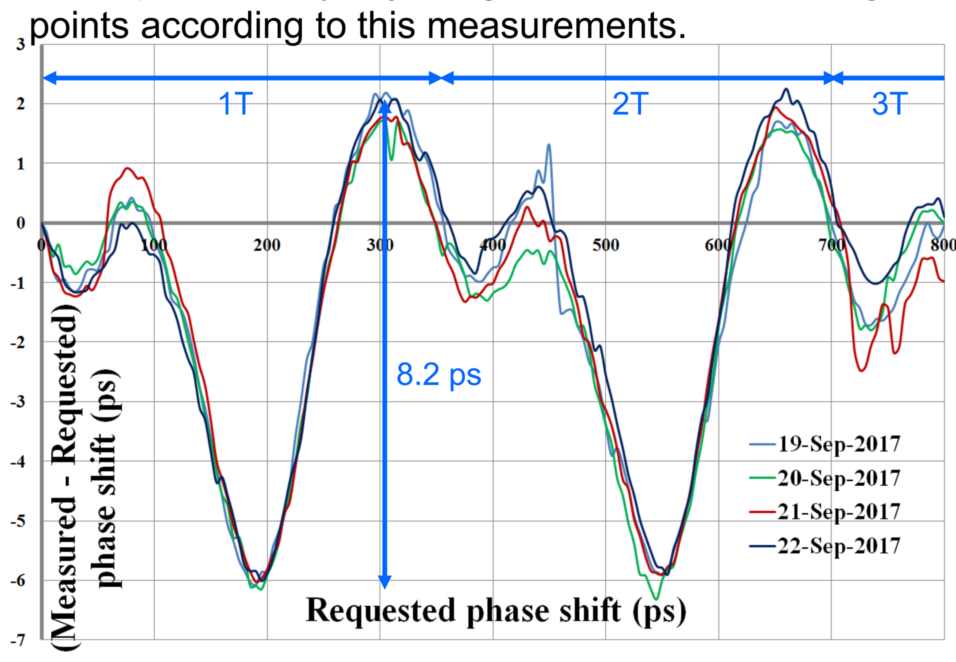


Figure 5: (measured - requested) phase shift.

Phase noise jitter

The phase noise jitter has been measured by connecting directly the TimIQ system to a Rohde&Schwarz FSUP Signal Source Analyzer.

	SOLEIL @ 88 MHz	MAX IV @ 3 GHz
RMS phase noise jitter [10 Hz – 10 MHz]	298 fs	177 fs

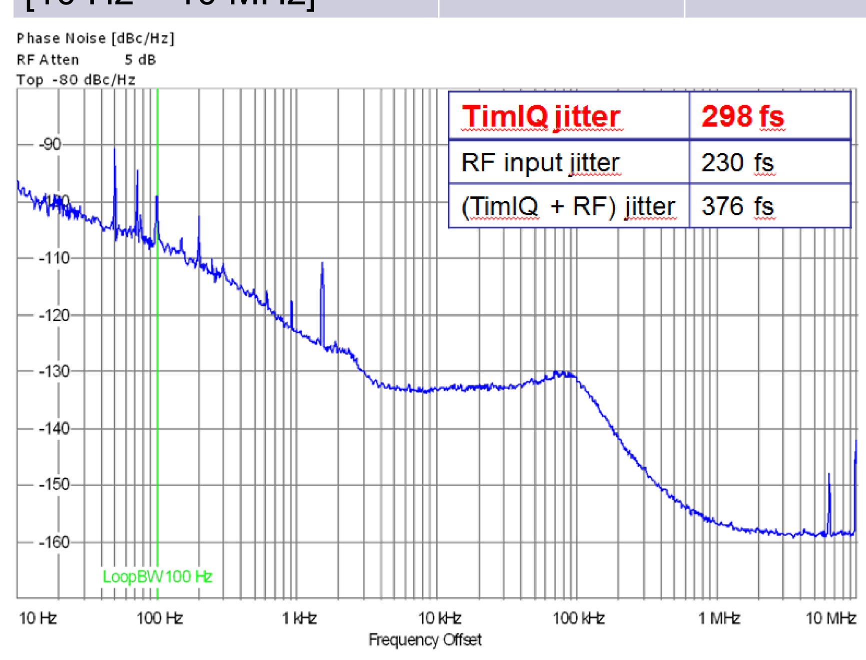


Figure 6: Phase noise jitter. SOLEIL configuration.