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SYNCHROTRON MASTER FREQUENCY RECONSTRUCTION FOR SUB-NANOSECOND TIME-RESOLVED XMCD-PEEM EXPERIMENTS

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Abstract

The timing and synchronization system at the ALBA synchrotron facility is based on the well-established event-based model broadly used in the particle accelerator facilities built in the last decade. In previous systems, based on signal model architecture, the master frequency was distributed using a direct analog signal and delayed at each target where the triggers were required. However, such strategy has proven to be extremely expensive and non-scalable. In the event-based model, the data stream is generated at a continuous rate, synchronously with the master clock oscillator of the accelerator. This strategy improves the flexibility for tuning the trigger parameters remotely and reduces the costs related to maintenance tasks. On the other hand, the absence of the pure RF signal distributed in the experimental stations implies much more complexity in the performance of time-resolved experiments. Abstract here explain how these difficulties have been overcome in the ALBA timing system in order to allow the signal reconstruction of the RF master frequency at the CIRCE beamline.

INTRODUCTION

The pulsed nature of synchrotron light can be potentially used for time-resolved experiments in highly dynamic systems. An excitation of the sample which is synchronous with the beam pulses allows acquiring static images using detectors that usually need a relatively long time for integration. The entire dynamic response of the system is then obtained by the subsequent analysis of measurements with different phase settings for the excitation (i.e., different delays between excitation and detection).

This methodology is used in ALBA CIRCE beamline in the research of the magneto-elastic dynamics by photoemission electron microscopy with x-ray magnetic circular dichroism (XMCD-PEEM). The magneto-elastic effect has been measured for Nickel microstructures under time-dependent elastic deformation at the sub-nanosecond timescale produced by a surface acoustic wave (SAW) in a piezoelectric substrate [1,2]. The responses of the magnetic microstructures at specific phases with respect to the sinusoidal excitation are acquired by synchronizing the SAW with the RF master frequency (499.654 MHz) of the accelerator.

Apart from the synchronization of the SAW excitation with the beam pulses, further requirements to obtain measurable deformations with reasonable accuracy are: first, a signal power reaching the sample of at least 100 mW (20 dBm) and, second, a signal jitter defined between the master oscillator and the SAW filter excitation smaller than 100 ps.

Moreover, a technical issue is the need to transfer the synchronism signal to the PEEM sample environment, in Ultra High Vacuum (UHV) and at High Voltage (HV), typically -20 kV. A fibre optic analog link available in the RF range provides complete galvanic isolation, preventing damage of expensive parts of the setup by propagation of arcs generated between the sample and the first microscope lens.

SYNCHRONISM STRATEGY

At ALBA, where an event-based timing system is used, the RF signal of the master oscillator is not pre-distributed around the synchrotron facility. Thus there is no straightforward implementation like in signal-based timing systems which however imply large costs in the installation, signal conditioning and maintenance. Alternatively the reconstruction of the master frequency from the present event-based timing system results in a smart solution. This option is more flexible, scalable, and easier to maintain.

Event-Based Timing System

In the ALBA event-based timing system [3,4,5], an event generator (EVG) produces a continuous data stream, synchronous to an external clock of 125 MHz that is one fourth of the accelerator RF. The sequence, composed by event frames (words), is transmitted by a tree structured fibre-optics network towards all the points where timing is required (see Figure 1). Fan Out units are responsible of distributing the event code by producing multiple identical data stream outputs from one event stream input. In the destination points, Event Receivers (EVR) decode the event frames and generates output pulses with configurable characteristics, such as delay and pulse width. This procedure provides full flexibility to change trigger parameters and a much easier maintenance. The output triggers are phase-locked with the clock reference with only a few picoseconds jitter, and are therefore synchronized to the master oscillator.

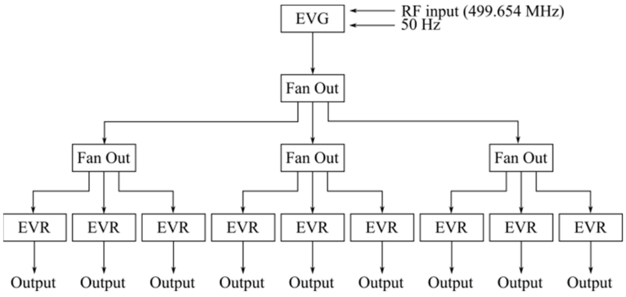

Figure 1: Event-based timing system topology.

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The presence of the timing system in all beamlines at the ALBA synchrotron was already planned in the installation phase, even where it was not requested for experimental purposes for first operation. Hence the upgrade of the PEEM beamline to perform time-resolved experiments has been (relatively) easy and fast. The transmission of the revolution clock signal of the ALBA storage ring (1.115 MHz), already implemented in the timing system, has been used for the synchronization of the SAW excitation, since it is a pure divisor of the master frequency.

Frequency Reconstruction

The frequency recovery of 499.654 MHz is achieved by an analog signal generator N5171B from Keysight with a specified 100 fs jitter close to 500 MHz. The signal generator, equipped with the optional upgrade 1ER, allows phase locking to an input reference not only at the typical 10 MHz but in the full range between 1 and 50 MHz. This option makes the revolution clock a compatible reference input, as shown in Figure 2.

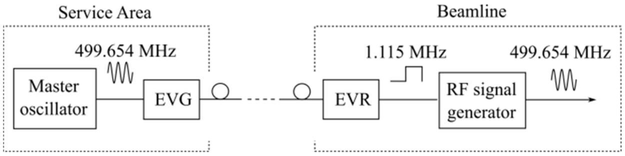

Figure 2: Basic topology for master frequency reconstruction using the revolution clock as the input reference for the signal generator.

The main advantage of this instrument compared with cheaper options (e.g. PLL) is the easy tuning of the amplitude and phase, either manually or remotely via the TANGO control system [6]. In addition, the instrument capabilities in terms of capture range (maximum frequency range) and phase locking to the input reference (maximum frequency jumps) are suitable to support RF variations generated for the compensation of beam orbit shifts in the storage ring [7].

HARDWARE ARCHITECTURE

In this section, the technical challenges to bring the signal from signal generator to the sample holder at -20 kV are described. In particular, electrical connections are ruled out by the great potential difference, and it is mandatory to carefully select the setup and its components for an easy and low-cost replacement in case of an eventual spike during the operation or sample manipulation.

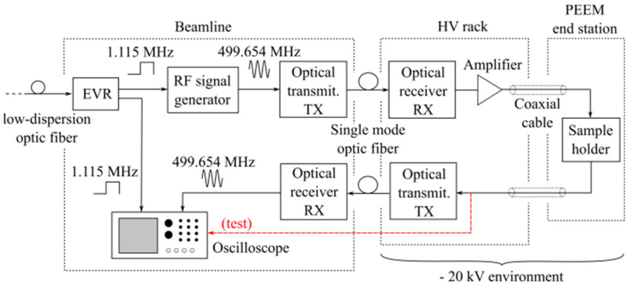

Figure 3: Diagram of the setup used for synchronous 500 MHz excitation of the SAW, in the configuration used to monitor the signal under measurement conditions.

The Figure 3 shows the hardware setup of the experiment. The galvanic isolation between potentials is achieved by an RF analog link available for transmission over single-mode optical fibre. The integration of this device in the setup was found as a flexible and easier solution than using a commercial optocoupler, since they are connected by optical fibres with no further mechanical restrictions.

From the HV rack, the signal is transmitted to the sample holder by a long RG-174 coaxial cable with a considerable attenuation (≈ 10 dB). To compensate this loss, as well as the reduced high frequency conductivity of the final PEEM UHV feedthrough, the signal is amplified by a commercial Mini-Circuits RF amplifier (model ZHL-20W-13+) with 50 dB fixed gain and 41 dBm maximum power. A 10 dB attenuator (model VAT-10+) before the amplifier optimizes the dynamic range and reduces de jitter noise at the output. All the elements in the signal path have a characteristic impedance of 50 Ω to avoid reflected signals.

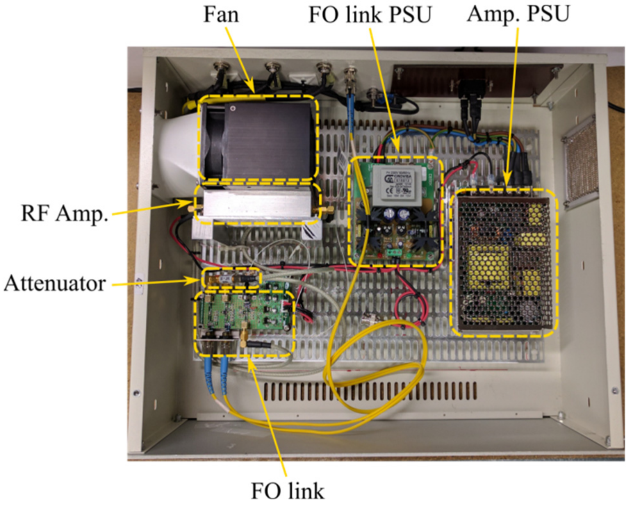

Figure 4: Components installed in the 3U rackable box to fit with PEEM HV rack space requirements.

Due to limited space in the PEEM HV rack, a compact instrument has been designed to integrate all the components inside a standard 3 unit rackable box (see Figure 4). Thus, the installation and removal of the setup whenever the experimental setup requires are faster. This box provides the fibre optic analog link (including one transmitter and two receivers), the RF high power amplifier, and their corresponding power supplies. A linear power supply is provided to improve the signal integrity and reduce ripple noise introduced to the fibre optic analog link.

Fibre Optic Analog Link

The fibre optic (FO) analog link is an in-house development which constitutes a key element in the SAW experiments setup. Two important requirements for an instrument exposed to potentially damaging spikes generated during the experiment are: (1) cost-effectiveness and (2) easy replacement. For that reason, a custom design integrated in stackable box has been the preferred option, instead of using high-performance available commercial instruments.

The main components in the design are the low cost transmitter and receiver AFBR-1310Z/AFBR-2310Z from Avago. The optical transmitter based on a Fabry-Perot laser diode allows multi GHz analog communication and operates at a nominal wavelength of 1310 nm (infrared). Both transmitter and receiver are available in a compact package easy to be integrated in a printed circuit board.

The ALBA-designed fibre optic analog link is built on an FR4 PCB substrate and it has a frequency operation range between 40 MHz and 1.1 GHz with a gain flatness of ±3 dB. The gain at 500 MHz is 11.8 dB and the output power at 1 dB compression is about 2.6 dBm (see Figure 5). The instrument includes a second optical receiver with a pre-amplification stage of 20 dB.

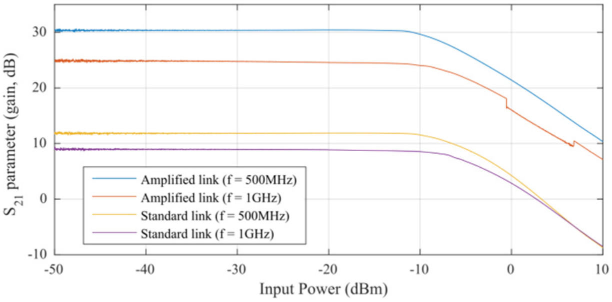

Figure 5: Gain as a function of the input power of the fibre optic analog link measured at 500 MHz and 1 GHz.

RESULTS

The conceptual design for the SAW excitation synchronization using the event-based timing system was first validated in the laboratory setup. Figure 6 shows an infinite persistence acquisition of the original and the reconstructed 500 MHz signal with the trigger configured at the EVR reference output. As a result, no effective time shift occurs in the reconstructed waveform, meaning the synchronization is correctly performed.

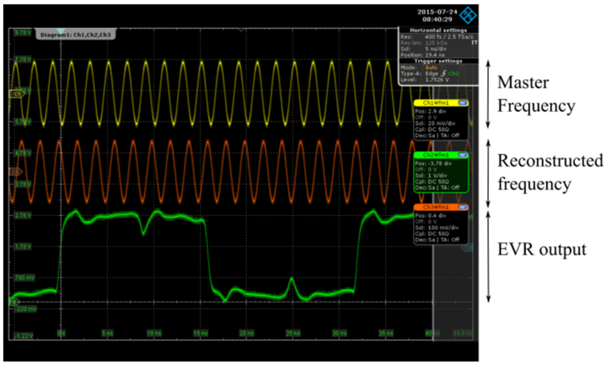

Figure 6: Laboratory proof of concept of the synchronism strategy using the timing system. A signal generator simulates de master frequency and an EVG-EVR pair generates the output triggers. Pulses of 31.25 MHz from the EVR output are used as a reference input for the second signal generator to create a 500 MHz sinusoid phase-locked to the master frequency.

The time-resolved experiments accuracy is mainly related to signal power and jitter behaviour at the sample position. Those parameters are measured at the coaxial cable end after the sample holder (displayed as “test” in the Figure 3) and estimated by subtracting the attenuation (≈ 20 dB) for the cable, the UHV feedthrough (passed twice), and the SAW substrate itself.

The results are shown in Figure 7. The jitter, given in terms of the full width half maximum (FWHM), is not measured with respect to the master oscillator but to the EVR output. It can be proved that the major contribution to noise is given by the experimental hardware and the jitter added by the timing system is considered negligible.

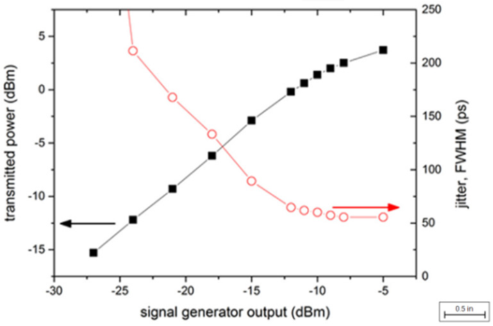

Figure 7: RF power (left axis) and jitter (right axis) for a 500 MHz transmitted signal through a short circuited sample holder in the PEEM end station measured through the “test” path (see Figure 3). Jitter measured with respect to the EVR output.

As presented in Figure 7, a signal generator output power greater than -15 dBm results in a measured jitter smaller than 100 ps. The maximum power transmission achieved is 24 dBm (250 mW), limited due to the saturation of the RF amplifier, with a stated jitter of 56 ps. These values for the jitter are in good agreement with the measured upper limit of the total temporal smearing in the

XMCD-PEEM experiment, which is below 80 ps (including the photon bunch length).

SYSTEM UPGRADES

The hardware architecture here presented has permitted the development of new designs in order to perform more advanced experiments of scientific interest at XMCD-PEEM.

Second Channel Source for Standing Surface Acoustic Waves

Two-channel architecture for SAW excitation has been put into operation in order to allow the measurement of tuneable SAW interference patterns. This setup enables the excitation of SAW from two opposite transducer electrodes with independently adjustable phase and amplitude.

The new hardware architecture duplicates the components present in the single channel architecture, with a few differences, as shown in Figure 8. In order to adjust the power and the phase of the waves independently, a second signal generator is added. Nevertheless, there is no need for the variable input reference option for this second signal generator since the instruments can share their internal 10 MHz reference. On the other hand, following the previous architecture, a bi-directional coupler placed after each RF amplifier has been introduced in order to still obtain a diagnostic of the signal sent and transmitted through the sample.

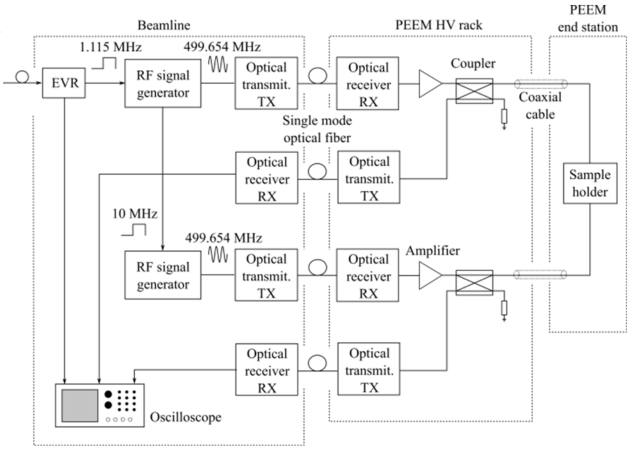

Figure 8: Block diagram of the hardware architecture for 2-channel standing SAW excitation in the PEEM experimental station.

High Speed Fibre Optic Digital Link for Pump-and-Probe Experiments

A new concept of experiments based on the pump-and-probe methodology is being developed in order to use frequencies other than 500 MHz for the sample excitation. A particular filling pattern in the storage ring bunches is combined with a digital signal which triggers an electronic “beam blanker” in order to modulate the detection of electrons in the PEEM. A switching signal coming from the timing system, therefore synchronous to the master oscillator would be transmitted to a function generator in order to produce the blanker pulses.

CONCLUSIONS

This work addresses the problem to obtain the analog master RF signal in the experimental beamlines in a facility that uses a digital event-based timing system. This type of systems, which are currently widely adopted in modern particle accelerators, involves the codification of events synchronized with the master oscillator, which are transmitted and digitally processed at the destination points. In contrast to other solutions (e.g., the creation of a parallel RF signal distribution over the facility), the hardware architecture here presented integrates this signal into the existing event-based timing system via the analog reconstruction of the RF signal from the digital pulses of the timing system.

In particular, the setup used for time-resolved XMCD-PEEM experiments has met all the requirements and demonstrated high reliability and flexibility. The synchronization between SAW excitation and the beam pulses is an innovative solution resulting in a robust and flexible setup. Moreover, the capability to control remotely the signal generator by the control system allows the automatization of scans over different phases and input powers for the SAW excitation.

The important role of the fibre optic analog link used to transmit the RF signal and provide at the same time the galvanic isolation between different potentials has been pointed out. A compact instrument has been developed to fit the limited space available in the PEEM HV rack and connected to other instruments by optical fibres. In addition, the fibre optic analog link is now also being used in other applications in ALBA, for instance as a diagnostic of high frequency optical signals at the LINAC.

Finally, the described application in PEEM can be scaled to other experimental beamlines with few increment of cost, what foresee new possibilities in the study of dynamic systems using the time-resolved or the pump-and-probe techniques. Furthermore, the integration of new experiments into the existing Control System will be much easier compared with the pure single-based solution.

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