Minutes of the 29/06/21 meeting on the ENR – MFE-IST-01

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Meeting objective: first discussion on the time synchronization of WEST profile reflectometers

NB: People not familiar with WEST reflectometry and WEST timing should refer to the annexes for more information.

There are 3 steps to ensure that the WEST reflectometers are synchronized:

1. Share the same 10 MHz clock
2. Ensure that the triggers are received at the same time in each diagnostic cubicle
3. Ensure that the diagnostic sweeps are performed at exactly the same time

Prior to any work, a first task is to connect the reflectometers to the same chronology board.

Share the same 10 MHz clock

The WEST chronology is based on a 100 MHz clock. However, this clock is not distributed; the current electronics for clock recovery installed in the diagnostic cubicles only provides sub-sampled clocks at 1 & 2 MHz. A new electronic board based on a more recent Clock and Data Recovery integrated circuit is currently being studied to provide a 10 MHz recovered clock in the cubicles.

Work and equipment need to be evaluated

Ensure that triggers are received at the same time

As the length of each optical link between each reflectometer and the Master chronology board is different, the receive time of a chronology code is slightly different for each reflectometers (tens to hundreds of ns). A method to evaluate the delay is to send back the trigger to the chronology board and then compare the echo times for the 3 reflectometers.

Delay times can then be introduced (software or delay line) to minimize the time differences between the 3 echoes. At CERN, state of the art synchronisation technology allows enables reaching sub-nanosecond precision, aiming at a few tens of picosecond between various detectors.

Work and equipment need to be evaluated

Ensure that reflectometers perform sweeps at the same time

Even if the trigger is received at the same time for each reflectometer, they are not using the same AWG, nor the same electronics and the waveguide lengths to the plasma are quite different. Using identical cables (several meters), one can collect the AWG signal on a scope to evaluate the time delay between the different reflectometers.

Delays can then be introduced in the reflectometer control to synchronize the sweep of every reflectometers.

This step does not require any new equipment.

Annex: WEST reflectometers and WEST chronology

1 WEST profile reflectometers

1.1 Profile reflectometers

West is equipped with three sweep reflectometers:

1) The edge profile reflectometer has two bands: V & W. The W band is in X-mode, while the V band (50-78 GHz) is most of the time in O-mode. Both channels are swept simultaneously and perform ultra-fast sweeps (acquisition sampling frequency 1GHz), down to 1µs, the dead time between profiles can be as short as 0.25 µs.
2) The core reflectometer covers the range 105-155 GHz (D-band) in X mode. The profile channel can performs ultra-fast sweeps using a similar 1 GHz acquisition system.
3) The antenna reflectometer is dedicated to the measurements of the density profile in front of the ICRH or LH antennas. It is "portable" and can be plugged to a LH coupler, or one of the 3 ICRH antennas. The reflectometer is being upgraded to operate in the W band. The acquisition sampling rate is 100 MHz, the sweeping time is typ. 10 µs. Thanks to short time-delay, the sweeping time can probably be reduced to 5 µs, or maybe less.

1.2 Implantation

The edge reflectometer is located in port Q3A, the core profile is 140° apart in port Q5B. The antenna reflectometer has been only used on the LH antenna, but it can be moved around the torus to be plugged to ICRH antennas, see Figure 1.

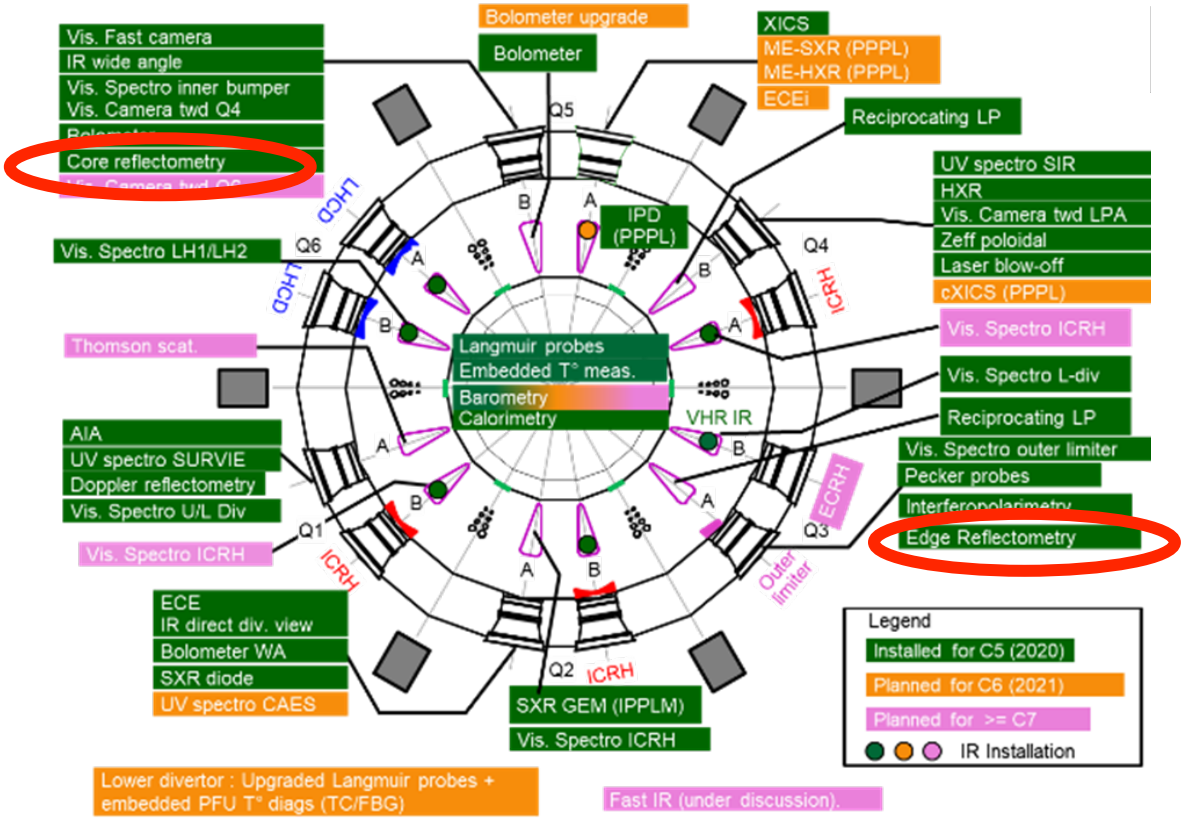

Figure 1: Implantation of the reflectometers and heating antennas on WEST

1.3 Reflectometer clock reference

Each reflectometer is driven by an arbitrary form generator that perform continuously sawtooth like sweep with a short dead time between pulses (typ 0.25 µs). The acquisition is triggered by the WEST chronology. To avoid time drift between the AWG and the acquisition sampling system, the AWG and the acquisition card share the same 10 MHz reference. Currently, each reflectometer has its own 10 MHz reference.

2 Pulse timing on WEST

2.1 WEST chronology

The pulse timing on WEST is based on a precise 100 MHz clock. This central chronology emits a reference clock at 1 & 2 MHz (division from the 100 MHz clock). The signal is distributed to 3 chronology boards. The diagnostics and other elements that use the WEST timing are connected to one of those boards.

The WEST chronology emits regular triggers (eg: every 1024, 2048, 4096 … µs) and event triggers (either emitted at a pre-set time or associated to a plasma event). The event triggers are set by the session leader and they are included in the Plasma Control System (PCS). Each trigger is identified by an 8-byte code. The pulse count starts when the chronology code ORIGINE is emitted. At t=32s, the plasma is ignited (IGNITRON code).

During the preparation phase, the reflectometer parameters are downloaded to PC that controls the reflectometer and then transfer to the AWG that drive the profile microwave source. The AWG is set in a GATE mode, i.e. it waits for a TTL trigger to activate the voltage and synchro outputs. The ORIGIN code is usually used to activate the AWG outputs as it allows 30s for the system to stabilize before performing a measurement. Acquisition can start 1 second before ignition to get the inner wall echo or 1 or 2 s after the Ignitron code. The data are downloaded to the WEST database at the end of the pulse.

2.2 Sweep acquisition

The reflectometer can operate in continuous sweep mode or in burst mode:

- **In continuous mode**, a profile is recorded at regular time intervals. After the reception of the trigger code, the chronology decoder installed in the reflectometer cubicle emits a hard trigger. This hard trigger enables the next TTL emitted by the AWG to trigger a profile acquisition (see Figure 2). The acquisition system store the pulse time of each profile initial point to date the profile.
- **In burst mode,** hundreds to thousands of profiles are measured consecutively. This measurement is triggered by an event trigger. The hard trigger emitted by the chronology decoder enables the next TTL emitted by the AWG to trigger the recording of hundreds of profiles consecutively, cf Figure 3. Only the time of the 1st point of the 1st profile is dated. To ensure that the acquisition system and the AWG remain synchronized, they share the same 10 MHz time reference.

3 Synchronization of WEST reflectometer

Currently, WEST reflectometers share the WEST data chronology and the 1 MHz clock and hence receive the WEST triggers at roughly the same time (µs precision), but they are not perfectly synchronized:

- Currently, each reflectometer has its own 10 MHz reference clock. This could be an issue in the burst mode as only the first profile of the series is dated; subsequent points are dated by the 10 MHz clock ,which could lead to a time drift for long burst acquisition.
- The time codes emitted by WEST chronology does not arrive exactly at the same time in each reflectometer cubicle. It can be issued from different chronology boards, and the delay

depends on the length of the optical link between this board and the cubicle. Moreover, each reflectometer has its own electronics and its own AWG (different manufacturer) leading to different time response.

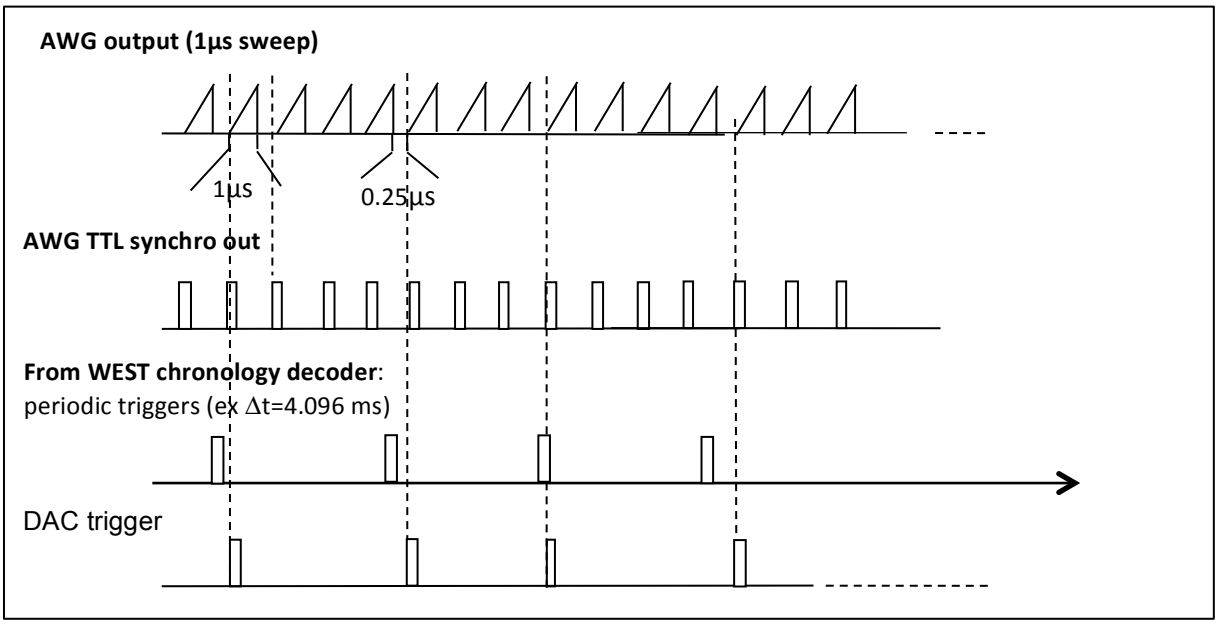

Figure 2: trigger sequence in the continuous mode

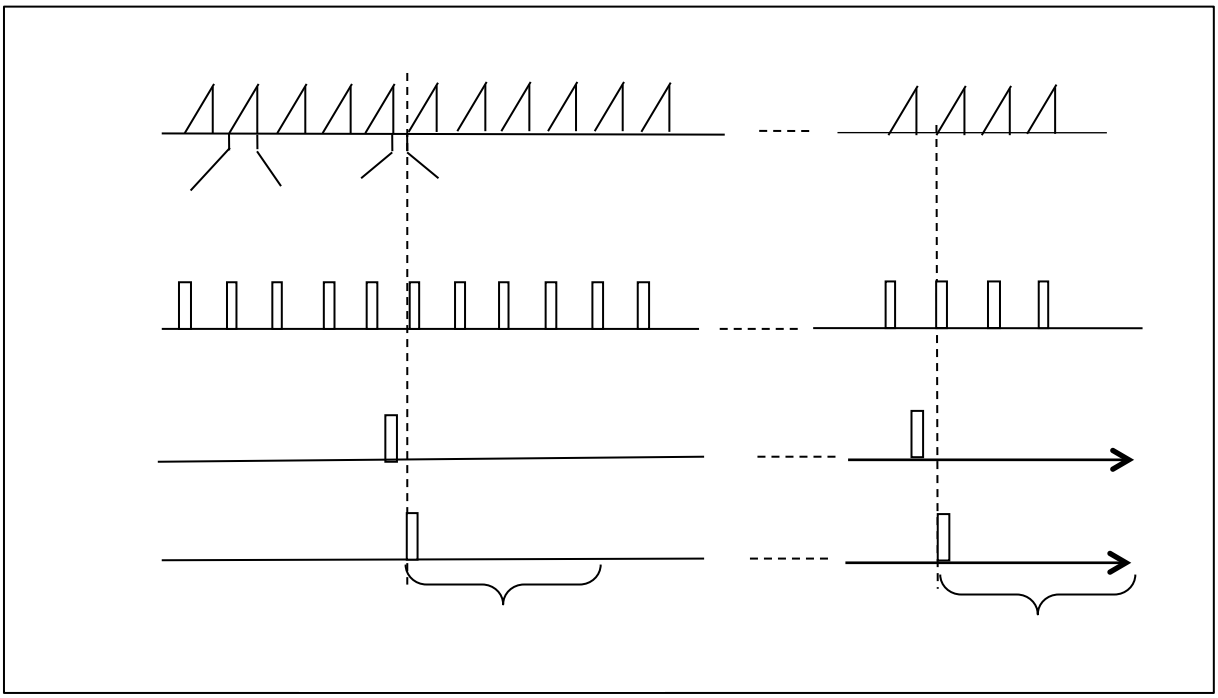

Figure 3: trigger sequence in the burst mode