TIME AND PHASE SYNCHRONIZATION AT ESS

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Abstract

ESS is a next generation spallation source to be built in Lund, Sweden. It is a green field laboratory, and as such it has the opportunity to establish one central timing reference for all systems, from control systems through reference phases for the accelerator RF generators to the scientific instruments at the detector. We will here present the proposed architecture for this timing and phase reference system.

INTRODUCTION

The European Spallation Soure, ESS, will be built in Lund in southern of Sweden. It is a neutron spallation source, with a 2.5 GeV pulsed proton accelerator aimed at a rotating tungsten target. The neutrons produced by the spallation process in the target are guided to 22 experimental stations located radially at various distances. The whole installation will run under an EPICS control system. A timing system will send out events and synchronize the experimental stations and their rotating neutron choppers to the accelerator pulses. The accelerator runs at 14 Hz with a pulse length of 2.86 ms.

ESS is a green field facility, i.e. there are no requirements to interface the RF, control or timing systems to any legacy systems. This makes it possible to have one central master oscillator for all the systems, and thus have them all phase locked to each other.

The accelerator consists of a normal conducting part and a superconducting part. The different accelerating structures are energized by RF at two different frequencies: 352.21 MHz for the low energy part, and 704.42 MHz for the high energy part. The baseline design is that each cavity will have one RF amplifier, typically a tetrode or klystron, and one dedicated LLRF system [1].

MASTER OSCILLATOR

The Master Oscillator at ESS will supply both the reference phase for the RF systems and the master timing reference for the timing and control system. This makes it possible for ESS to have a phase lock between the RF signals, i.e. the bunch arrival time, and the timing system events. The choice has been made to run the timing system at a fourth of the fundamental RF frequency used in the low energy parts of the accelerator.

The fundamental frequency of the master oscillator will be 352.21 MHz. The timing system will operate at 88.052500 MHz [2]. The second RF frequency of 704.42 MHz is generated by doubling the fundamental frequency.

The choice of a timing frequency of 88.0525 MHz gives a granularity, or tick interval, of timing events of 11.357 ns. The repetition rate and pulse length are constrained to be integer number of ticks, in this case they will be 6,289,464 and 251,830 number of ticks respectively. As the RF frequencies and pulse rate and length for the installation were chosen independently, this will not give the exact length of the two latter. The errors in both are below 1 ppm.

Design

The Master Oscillator must fulfill two basic requirements; it must have a low phase noise and be long term stable. Studies of typical available oscillators show that these two criteria are not available off the shelf. To achieve the low close in phase noise a crystal oscillator will be used, placed in a temperature controlled enclosure, an OCXO. These devices show excellent low close in phase noise, but will drift in frequency over time. If the master oscillator was only used to generate the RF reference phase signal, this would be a small problem as the absolute frequency is of less importance. But as the frequency reference will also be used to generate the time stamps for the accelerator, a drift over time would lead to the accelerator time stamps to not align with the UTC time. Thus the OCXO will be locked by a PLL to a stable frequency reference. Typically this will be either a rubidium or cesium clock. This in turn will be locked to the GPS system to keep track of the official UTC time and logging the discrepancy between the internal ESS time and UTC time.

The OCXO will run at 10 MHz. This signal will also be directly available from the MO as a frequency and phase reference for standard test instruments.

The crossover frequency for the PLL loop will be chosen so that the good phase noise characteristics of the crystal oscillator are not compromised. As this time constant will be very long, digital filters will be used. The phase detector and the filter will be implemented in a FPGA, with the output taken from a high quality digital to analog converter. The output will be further low pass filtered to minimize the risk of introducing any noise on the control signal to the OCXO.

A fractional-N PLL circuit will be used together with a VCXO to generate the 352.21 MHz signal for the RF phase reference system. The 704.42 MHz signal will be generated by frequency doubling of this signal. The

 ISBN 978-3-95450-115-1

outputs will be buffered by output amplifiers before being fed to the RF phase distribution system.

RF PHASE REFERENCE DISTRIBUTION.

The RF phase reference distribution system is primarily used as a reference for the 200 LLRF systems that will be used in the accelerator. The baseline for the RF phase reference distribution is a coaxial line in the tunnel along the accelerator, with one tap for each cavity. The two signal cables, one from the reference tap and one from the cavity probe, will be bundled together as they are distributed from the tunnel to the klystron gallery and the appropriate LLRF unit. This will ensure that they have the same temperature and the same phase drift over time.

The beam instrumentation electronics will also need reference signals. These will be distributed from the LLRF systems.

REDUNDANCY

As the master oscillator function will be critical to the operation of ESS, it will be implemented as a fully redundant system, with a hot spare running in parallel to the primary clock. The switchover procedure will be designed so that the downtime due to MO failure will be minimized.

FURTHER DEVELOPMENT

The use of down-conversion and sub-sampling receivers in the LLRF and beam instrumentation electronics is being investigated. Depending on the choice, additional signals may be needed to be supplied from the master oscillator. Alternatively, the needed LO signals may be generated locally by locking PLL loops to the recovered clock from the timing system. Different architectures will be investigated.

REFERENCES

[1] S. Peggs, "ESS Conceptual Design Report", ESS 2012-001, European Spallation Source AB, 2012.
[2] A. J Johansson, "Timing System Frequency Choice for ESS", ESS Technical Notes, ESS/AD/0040, European Spallation Source AB, 2012.