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WALL CURRENT MONITOR USING PXI AND LABVIEW AT CERN

C. Charrondière, R. Limpens, M. Delrieux, CERN, Geneva, Switzerland

Abstract

The new data acquisition system for the PS ring wall current monitors installed in the PS is able to perform high frequency measurements of a beam bunch up to a frequency of 2.7 GHz. This is an important improvement, since the oscillating signal within the bandwidth 500-700 MHz, is related to losses of a beam bunch. The losses could be eventually reduced by measuring the frequency and classifying the cause of the oscillations. The PXI-5661 is used to carry out spectral analysis of this signal. The acquisition is performed on a PXI running LabVIEW Real-Time and synchronized using a trigger from the accelerator timing system.

INTRODUCTION

A wall current monitor (WCM) [1] is a device to measure the instantaneous value of the beam current (Figure 1 together with its working principle). As the beam travels through the vacuum pipe, it is accompanied by a current flowing along the inside of the pipe's wall, in the opposite direction of the beam current, which can be measured.

A new acquisition system for the CERN Proton Synchrotron (PS) ring wall current monitors has been installed to be able to perform higher frequency measurements of beam bunch transverse and longitudinal oscillations. The losses and instabilities can be understood and eventually mitigated by measuring the frequency and classify the impedance sources exciting the oscillations.

REQUIREMENTS

The main goal of this project is to acquire and view the wall current monitor data in time and frequency domains and to be able to identify different type of beam instabilities. A LabVIEW application running on a PXI real-time target is used to perform continuous and triggered data acquisition of a beam bunch and display the data on a viewer for the users.

Longitudinal Instabilities

The main limitations to the brightness of the beam of the PS for the future HL-LHC [2] beams are in general related to the longitudinal coupled bunch instabilities [3]. These oscillations occur in the relative low frequency domain, 0-20 MHz, and are related to the ten 10 MHz RF cavities impedance. Note that the purpose of these RF cavities is to accelerate the beam, which means that they are indispensable and their number cannot be reduced to mitigate the instability.

Principle of the Wall Current Monitor

The wall current monitor can measure the instantaneous voltage within a bandwidth of 100 kHz to 4 GHz of the beam current. In the PS at CERN three kind of Wall Current Monitors are present, which measure the following signals: vertical, horizontal and sum pick up voltages. Each signal could be used to identify beam oscillations, thus a different instability.

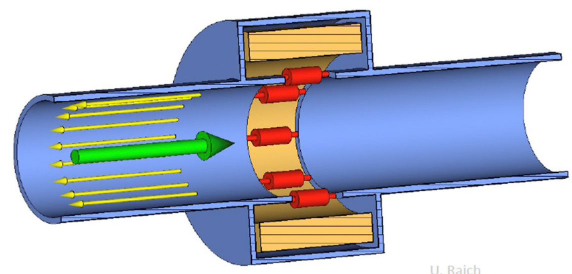

Figure 1: A schematic overview of a WCM. The green arrow represents the beam current, which is accompanied by its own image current (yellow arrows). A set of resistors (the red cylinders) generates a measured voltage. Ferrites, which are electrically insulators, (light brown section) forces the image current to flow through the resistors.

WALL CURRENT MONITOR OVERVIEW

The WCM application is deployed on a PXI system, which can be triggered by using a Control Timing Receiver (CTR) [4] card and the timing library ported to LabVIEW RADE [5] (Figure 2). The Target application is integrated in the CERN accelerators control system to profit of services such as the CERN accelerator logging [6] or to simply give the possibility to other applications in the Cern Control Center (CCC) to access the data published by the target application. The HOST application has been developed in LabVIEW using the RADE framework.

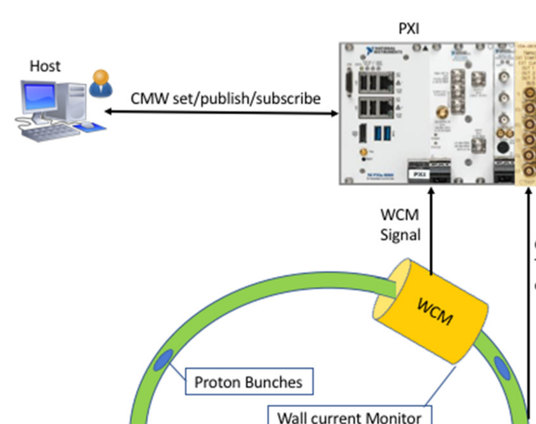

Figure 2: System overview.

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Hardware Description

A PXI chassis (PXI 1042Q) is an 8-slot holder for the PXI cards, PXI 5142, 5600 and 8250. Where the PXI 8250 is a system monitoring module that will monitor the health of the PXI system. To control these different cards a PXI controller is required, in this case a PXI 8108 is used.

The PXI-5661 is a modular 2.7 GHz RF vector signal analyser (VSA) with a wide bandwidth and digital down-converter. To be able to analyse the data in real time by the PXI-5142 the device uses intermediate frequencies (IF). High frequency signals are down-converted to the IF by the 5600 RF downconverter. Using self-calibration, the NI-5142 IF digitizer is able to adjust to frequencies other than those which it was externally calibrated for. The self-calibration adjusts the digitizer with respect to an on-board, high-precision voltage source, which means high accuracy acquisition can be maintained.

CERN General Machine Timing (GMT) on PXI(e) Systems

The CERN PS proton beams are produced at typically 1.2 second intervals and then delivered to different experimental setups within the accelerator complex or to the SPS. This process is called Pulse-to-Pulse Modulation (PPM) [7], which ensures a dynamically allocatable and reconfigurable distribution of the proton beams. Each CERN accelerator (Machine) has its dedicated timing network which broadcasts a constant Event Stream and a data channel (Machine Telegram) which provides UTC-synchronous and machine information to synchronize the PPM operations throughout the accelerator complex. A CERN-developed Control Timing Receiver (CTR) hardware module is installed into computer systems requiring precise synchronization with GMT events and the telegram information.

The timing library of the RADE framework enables LabVIEW users at CERN to configure a CTR module installed in a PXI(e) system [8] in order to trigger hardware from General Machine Timing (GMT) events and to generate UTC synchronous absolute timestamps (Figure 3).

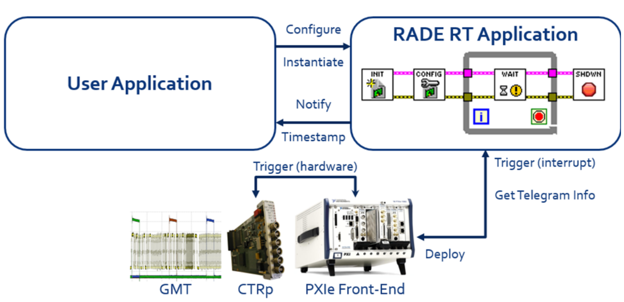

Figure 3: Timing library of the RADE framework.

Data Acquisition Modes

The wall current monitor application can fetch the data in two ways. Directly as power spectrum data or as I/Q data, which is basically raw data.

Power Spectrum data consists of a data structure (in LabVIEW terms: cluster) containing a start frequency f0, the size of each linear step Δf and an array of the power squared data. The power spectrum of the signal describes the distribution of power into frequency components. The advantage of using the predefined spectrum analysis RF Vector Signal Analyser (RFSA) blocks is that they are optimized for the LabVIEW environment and hardware.

In-Phase and Quadrature (I/Q) data is merely a translation of amplitude and phase data from a polar coordinate system to a Cartesian (X,Y) coordinate system. The disadvantage of I/Q data is that it produces many orders of magnitude more data compared to the power spectrum mode. This could be an issue for the network, regarding speed. In addition, transporting and acquiring I/Q data requires more RAM and CPU resources.

THE APPLICATION

The application acquires Radio Frequency (RF) signals and performs spectrum analysis. To accomplish this the application running on the Target system (PXI) requires to be optimized for performance. Therefore, the data acquisition (DAQ) LabVIEW application must be designed in a way that it requires minimal CPU resources. The second goal of the application is to present the acquired data and analysed data to its users. For this purpose, a display module has been developed, which focuses on user interaction called 'Host' (Figure 4).

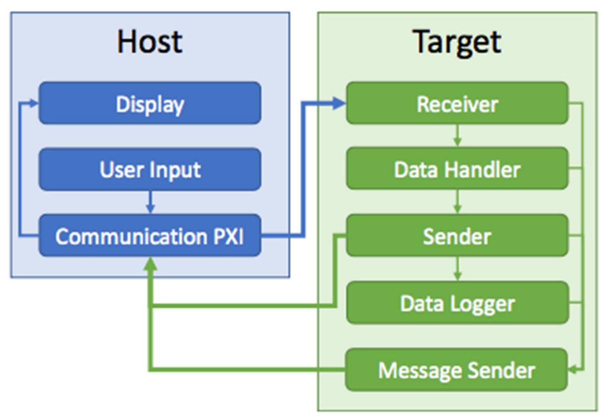

Figure 4: Simplified WCM application layers.

Communication

The Host's communication layers (Figure 5) contain various asynchronously called VIs (functions) that are dependent on the user input. These functions are divided in submodules and processes.

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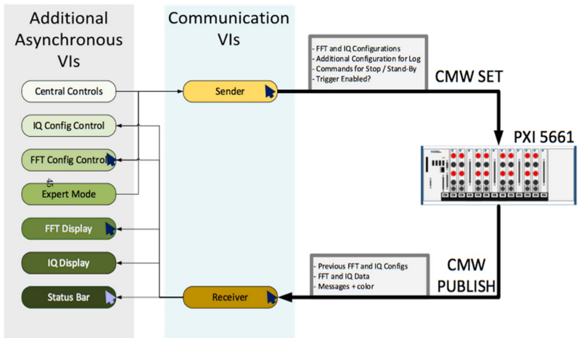

Figure 5: Host communication layers.

The Target operates by executing five main modules in parallel, where the top module is a master of the lower next slave module, as illustrated in Figure 6. In this way the topmost module "target:receiver" is the master of the "target:data-handler" and is the module "target:logger" the slave of "target:sender". Any module of the target, except the module itself, can enqueue messages to the "target:message-sender" module, which will publish the messages to the host. Therefore, this module is the slave of all target modules.

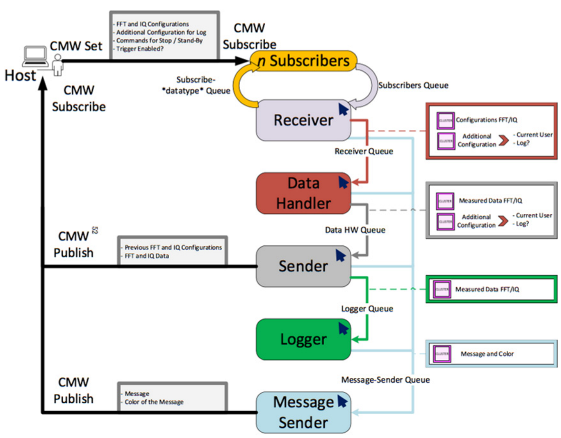

Figure 6: Target communication layers.

Graphical User Interface

The main user interface is modular and can load several panels. In the image shown the main user interface components (Figure 7) are marked by numbers: 1 is the "host:status-bar" module, 2 the "host:display-spectrum", 3 "host:power-spectrum-controls" and 4 the "host:central-controls" module.

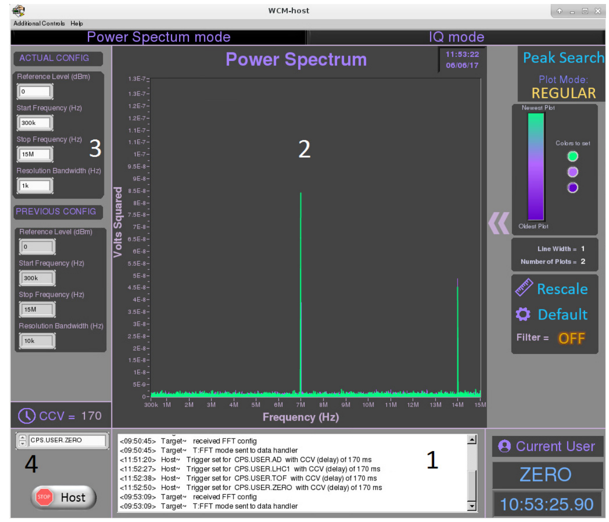

Figure 7: Main panel user interface.

Accuracy and Reproducibility

For absolute amplitude, the typical accuracy is ±0.6 dB for f < 2 GHz and ±1 dB for f > 2 GHz. Frequency limits are also applicable to the hardware, a range of 9 kHz to 2.7 GHz with a resolution bandwidth of 1 Hz to 10 MHz.

Reproducibility can be validated by performing a reference measurement over an extended period of time. The illustration (Figure 7) shows that the expected 7 MHz peak is stable over multiple measurements.

Dead Time

The WCM application uses looping to continuously perform triggered and continuous acquisition, see Figure 8, where the dead time is the difference between t0 and t1. Note that this timing issue is only valid for power spectrum read mode, since I/Q mode fetches the data from memory of the card PXI-5661. The dead time varies from 50 us to 400 us depending on the number of point the retrieve.

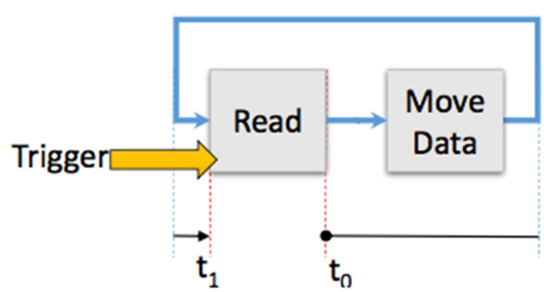

Figure 8: Illustration that indicates the dead time from t0 to t1 by iterating for the next power spectrum read.

CONCLUSION

The main goal of this project, to perform continuous and triggered spectral acquisition of a PS beam bunch and to provide a data visualization and analysis tool, has been accomplished by developing a LabVIEW application on a Real-Time PXI system with a Vector Signal Analyser. The

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acceleration of the beam has been visualized as seen in Figure 9.

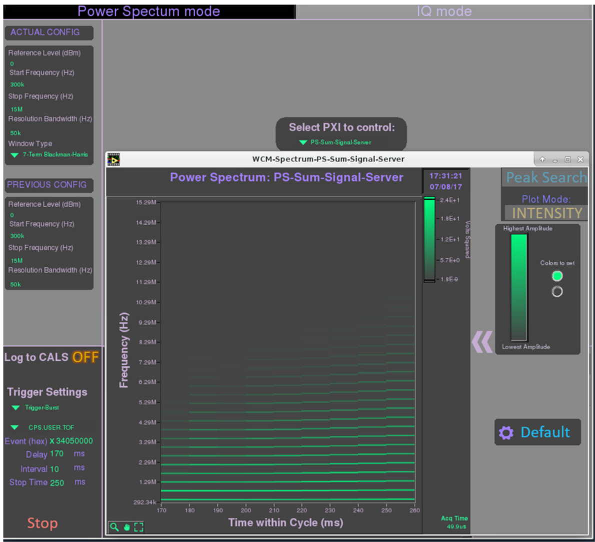

Figure 9: Example of a continuous power spectrum acquisition for an accelerating beam acquired by the WCM application.

With a typical setting (bandwidth 20 MHz) the signal can be acquired and the FFT calculated every 5 ms.

The communication between the two separated applications, RT target and visualization, was realized by using CERN's Controls MiddleWare (CMW), which provides a common software communication infrastructure for the accelerator complex.

During the development phase, the software and hardware functionalities were validated by performing a reference measurements with a high accuracy input signal and low harmonic distortion.

In addition to this first system, the users have requested two additional systems to cover the transversal pick-up signal instabilities in the same manner. These additional systems will have to be integrated into the visualization user interface.

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