Contribution ID: **193**

Type: **Poster**

Development of quad-channel high resolution digital picoammeter for beam diagnostics

Thursday 5 October 2023 17:40 (20 minutes)

In particle physics applications the photon beam interaction with various materials can produce electric charge which can be measured as current and be used to diagnose particle trajectories, beam intensity, beam profile, position, and stability. SIRIUS, the new 3 GeV fourth-generation Brazilian light source, will make use of hundreds of low-intensity measurement instruments. This work aims at showing up and discussing the design details, challenges and test results of a four-channel high-performance digital ammeter, applied for general-purpose beam diagnostics.

Summary (500 words)

High accuracy and high resolution low current measurements are a common demand for many beamlines attached to SIRIUS, the new 3GeV fourth-generation Brazilian light source. Due to femtoampere resolution measurements technical requirements and the need for a large number of diagnostic elements such as photodiodes, ionization chambers, and photon beam position monitors, we have developed a four-channel digital general-purpose current meter. The device is based on low-noise and extremely low input bias bipolar transimpedance amplifiers with eight selectable ranges (full scales from pA to mA).

This wide dynamic range is implemented by using the classical multirange transimpedance amplifier circuit, which makes use of high insulation reed relays to select different high-precision gain resistors on the amplifier stage. The circuit is followed by floating 2ksps, 24-bit Delta-Sigma analog-to-digital converters. The range selection, ADCs configuration, and digital data acquisition are managed by an ARM microcontroller. The data stream is sent through a 100 Mbps Ethernet link and can be synchronized by means of external triggering input and outputs. The electronics is prepared to bias the connected device up to 400 V using an external HV power supply.

This work aims at discussing the theory of very low current measurements focusing on explaining the several sources of errors that can impact the electronics performance. The component selection process and the adopted strategies to make a proper guarding, shielding, and PCB layout in such a way to effectively reduce static and dynamic errors are also presented.

The PCB was designed to guarantee extremely low leakage on the current path from the input connector to the transimpedance amplifier input pin employing guard ring tracks, planes, and metallic shielding driven by a guard buffer circuit, combined with PCB cut-outs and solder mask removal from sensitive region. Even using several low-current leakage techniques, a careful cleaning process was developed to improve the circuit' s accuracy.

The characterization results show that the achieved gain, temperature stability, accuracy, and noise performance are on the same order of magnitude as those of expensive commercial benchtop equipment. In low bandwidth applications the device was able to measure hundreds of picoampere with intrinsic noise of units of femtoampere (RMS). For many particle physics applications, the designed device could be an excellent low-cost multichannel choice.

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Session Classification: Thursday posters session

Track Classification: Module, PCB and Component Design