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GUARANTEEING THE MEASUREMENT ACCURACY IN Em#

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Abstract

ALBA, in collaboration with MAXIV, has developed a four-channel electrometer of 18bit deep with 8 ranges from 1mA to 100pA. The objective of accuracy in the measurements made clear from the beginning the need to compensate the components tolerances and its dependence with temperature. This paper describes the tests performed to characterize the acquisition chain, the automatic calibration developed and the hardware and software implemented to achieve the accuracy target. This implementation has been eased due to the high flexibility given by ALIN and Harmony [1] architectures used in the Em#.

EM# RETROSPECTIVE

Low current measurements are widely extended in Synchrotron light sources, like ALBA. The major need of electrometers in ALBA is for Front-Ends and Beamlines diagnostics. This need was identified during the construction of ALBA and the first version of the electrometer was designed [2]. This version was successfully installed in all ALBA beamlines and Front-Ends, but some beamlines went beyond using the electrometer as a detector. Besides the good precision achieved in the current measurements, this first version had some limitations that affected its functionality: synchronization performance, low ADC resolution, lack of calibration or temperature compensation, are some examples. In 2013, the need of a redesign a new electrometer electrometer was clear. The new instrument had to solve also a problem of obsolescence of the microprocessor board. The same year started the project of the second version of ALBA electrometer, Em# [3]. The first steps were defining an architecture which would give as much flexibility as possible and to avoid future obsolescence basing the design on standards and avoiding brand dependences. On that way, it was decided to use SPEC board from OHWR [4-5] and designed by CERN. In 2015, MaxIV Light source signed a collaboration agreement to join in Em# project. Finally, in 2016, 12 units in ALBA and 50 units in MaxIV were assembled.

ACCURACY OPTIMIZATION

One of the main targets of Em# was the improvement of its accuracy. The tests of first version of ALBA electrometer showed that the achieved precision exceeded expectations. The main reason of that precision was the Current amplifier (CA) low noise, equivalent or better than many state-of-art current amplifiers (Fig. 1). For that reason, the analogue part of electrometer was kept without including major changes. Some minor changes were optimizing the heat generation, enabling the offset correction foreseen in the first design with a DAC and the addition of temperature sensor accessible remotely.

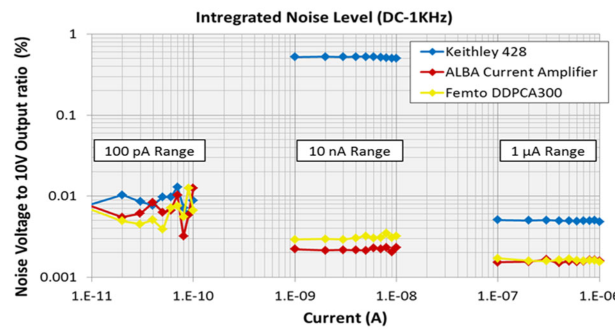

Figure 1: ALBA CA noise comparison with commercial electrometers.

One characterization showed that the noise measured in most of the ranges was so low that the ADC resolution was the limiting factor of the acquisitions. That lead to the decision of using a new the ADC with increased resolution of 18bits.

Another improvement implemented in the new Em# was the complete isolation of measurement ground respect the rest of grounds. This action minimizes the appearance of multiple ground loops which typically increase the noise of the measurements. The enhancement was not done in traditional way; it was decided to isolate the grounds after the ADC, isolating digital signals. A secondary effect of this architectural change was that it allowed measuring currents in environments were grounds needs to be biased. As this change had implications in the cost of the equipment and its auxiliary setup two versions of Em# were developed: one to work safely with HV bias (up to 1kV) and other to avoid the ground loops

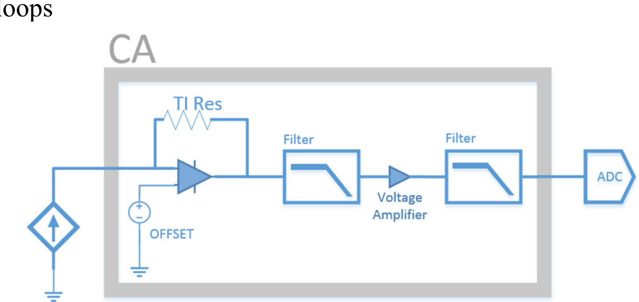

Figure 2: Schema of the CA between the current source and the ADC. The CA consists in a transimpedance amplifier with a gain, fixed by TI resistor and offset adjustment, a voltage amplifier and two low-pass filters.

COMPONENTS TOLERANCES

The first ALBA electrometer minimized the tolerances and temperature dependences in the design using matched pair resistors. However, as requirements in accuracy in-

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creased the need of implementing a software based calibration inside the instrument appeared as unavoidable.

Before starting the implementation of a software measurement correction the critical components were analysed for a better understanding of the CA dependencies. The most critical components were located close to the first amplification stage: the electrical discharge protections, the transimpedance amplifier, the gain resistors and the offset adjustment circuit. Figure 2 can help to locate the components.

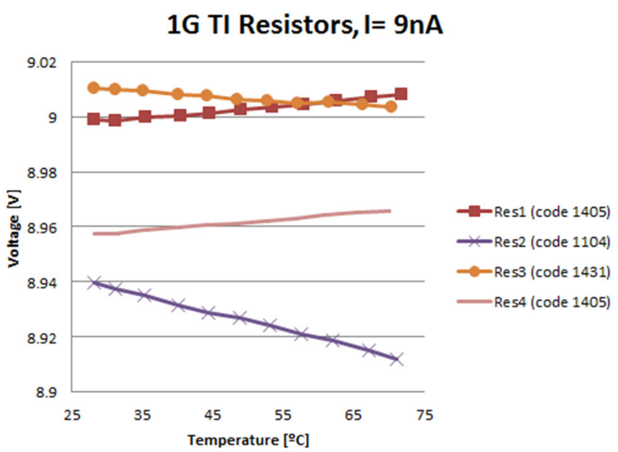

Figure 3: Study of temperature dependency of one of multiple resistors models analysed.

We did an isolated characterization of the first stage gain resistors versus temperature (Fig. 3). We surprisingly discovered that different units of the same resistor model could show negative or positive temperature coefficients even one could see a very similar tendency if the units came from the same production lot.

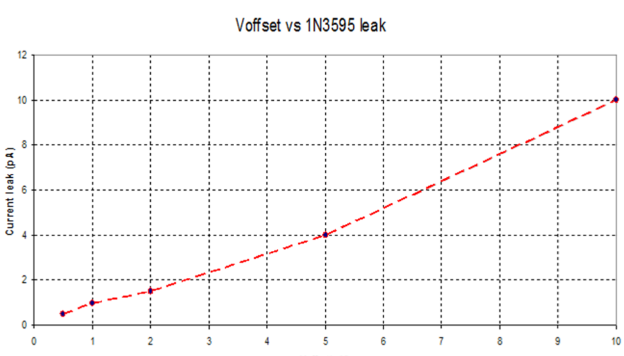

Figure 4: Plot of leakage current on 1N3595 diode versus offset voltage.

The second study was focused in the included discharge protection at each current input. The circuit is based on two small signal diodes 1N3595. These diodes generate a leakage current which depends exponentially on the offset voltage and temperature (see Fig. 4). Both dependences are difficult to separate, because the offset circuit generation also depends on temperature. That is why we did not try to disseminate its contributions since they were quite tangled.

CORRECTION ALGORITHM

The characterization of the current in open loop versus temperature showed that in lower ranges the exponential contribution of the protection diodes dominates whilst in higher ranges the linear contribution of the transimpedance resistors are higher. This can be seen in the following figures (Fig. 5 and 6).

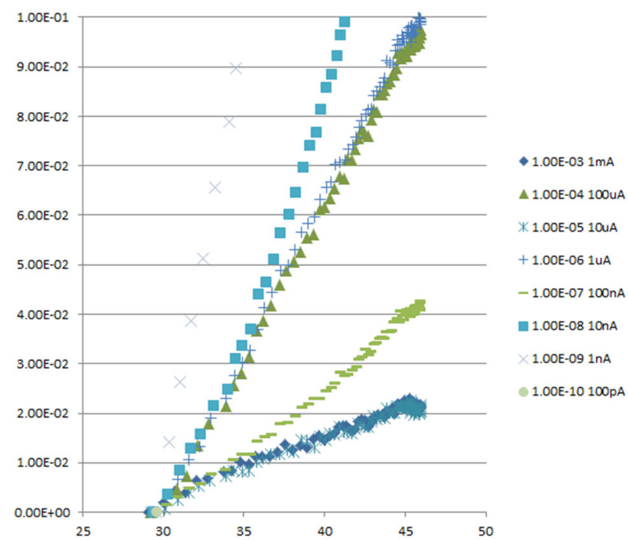

Figure 5: Offset current versus temperature, scaled to full scale.

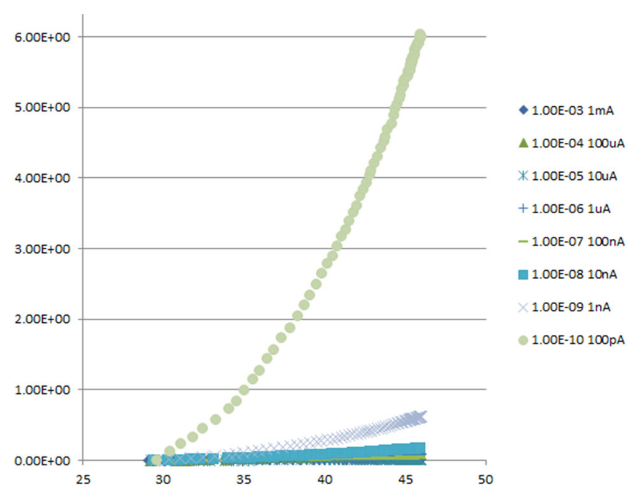

Figure 6: Offset current versus temperature, scaled to full scale. Lower ranges leakage current on diodes dominates.

The decision taken was to implement a correction algorithm of the offset and the gain modelling a linear behaviour with temperature. In case of a high accuracy needed in the lower ranges the protection diodes should be removed.

To implement such correction each CA include a temperature sensor close to this critical elements which reading is used to adjust the offset voltage to be applied. And in parallel a second correction is applied to compensate the gain dependency from temperature.

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CALIBRATOR

To guarantee operability and accuracy a design of a calibrator started. The calibrator generates a reference voltage using the voltage reference LTZ1000(see Fig. 7). This voltage reference with different resistors allows the generation of 8 different currents from 700µA to 70pA that allows calibrating all Em# ranges. A dependency with temperature bellow 0.1ppm in the range from 20ºC to 40ºC was achieved once the known gain resistor dependence was corrected.

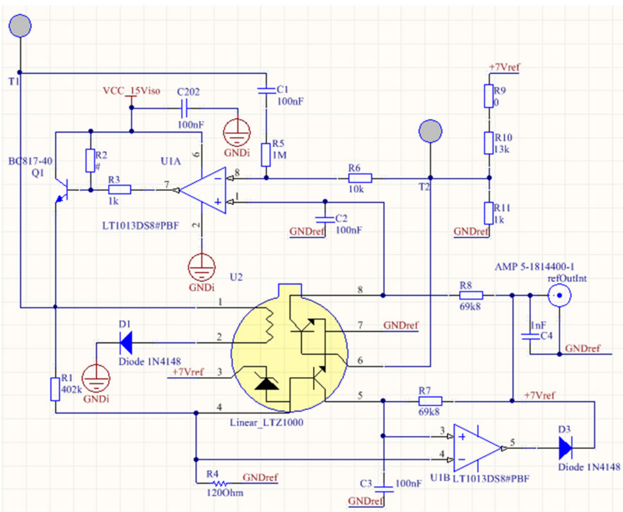

Figure 7: Schematic of voltage reference using the LTZ1000.

Therefore, to guarantee the calibrator accuracy lower than 1ppm requires calibration and correction of the reference currents of calibrator with the temperature. The work done in the CA showed that the resistors value depends linearly with temperature, so a linear correction is calibrated and stored in an internal EEPROM. The calibration is done with a Keysight 34470A multimeter and a Keithley 6517B electrometer. Figure 8 shows how calibrator looks like.

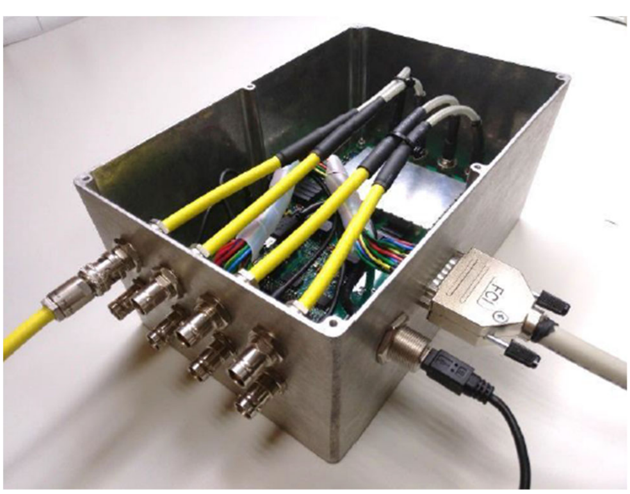

Figure 8: Calibrator.

CALIBRATION METHOD

The correction algorithm is based on a calibration values stored in an integrated EEPROM in each CA. The internal EEPROM allows 2 different calibrations storage: one reserved for a factory calibration and a second to let the users execute further calibration according with their calibration plan.

The implementation first measures temperature and the current in open circuit and adjust the offset voltage until 0 current is achieved. Then it injects a known current in the CA to calibrate its gain. This is done for each gain of transimpedance amplifier with the second stage voltage amplifier fixed to 1. The next step is to calibrate the voltage amplifier gains with the minimum gain on the transimpedance amplifier. This procedure is repeated at different temperature to characterize the temperature dependency.

The Em# includes script for an in-situ calibration. The script do the first measurement at power up and the second measurement when Em# temperature gets stable.

The values of temperature (T) and offset voltage (V_{OF}) in open circuit are used to calculate V_0 (offset voltage at 20ºC) and m (temperature coefficient to compensate offset voltage) in Eq. (1).

$$V_{OF} = V_0 \cdot \left(1 + m \cdot (T - 20)\right) \quad (1)$$

Then the reference current and the voltage read in the ADC are used to calculate the parameters β (tolerance of resistor nominal value R_N) and α (temperature coefficient) of transimpedance gain equation (Eq. (2)).

$$G_{TI} = R_N \cdot (1 + \beta) \cdot \left(1 + \alpha \cdot (T - 20)\right) \quad (2)$$

The temperature dependency of voltage gain is calculated following the same procedure.

CONCLUSION

Designing high accuracy instrumentation is a complex task. This paper summarizes the work needed to achieve that the improved accuracy target of the Em# electrometer could be assured in all cases.

Even concrete actions will necessarilydepends on the concrete instrument to be designed, there are different generic lessons that can be learned: the first one is that the investment of time in the deep characterization of an instrument of high accuracy is comparable with some design phases. The second one is that it is highly recommendable to design an internal architecture of the equipment that allows a flexible implementation of the possible dependencies that are found in the future. This has been the case of the Em# and thanks to its architecture flexibility now Em# is able to measure with requested accuracy comparable to the state-of-the-art electrometers.

REFERENCES

[1] M. Broseta *et al.*, "Present and Future of Harmony Bus, A Real-time High Speed Bus for Data Transfer between FPGA Cores", in *Proc. ICALEPCS'17*, Barcelona, Spain, Oct. 2017. doi:10.18429/JACoW-ICALEPCS2017-WEAPL01

ISBN: 978-3-95450-200-4 doi:10.18429/JACoW-PCaPAC2018-THP22

[2] J. Lidón-Simon *et al.*, "Low Current Measurements at ALBA", in *Proc. ICALEPCS'11*, Grenoble, France, Oct. 2011, paper WEPMS025.

[3] J. Avila-Abellan *et al.,* "Em# Electrometer Comes to Light", ALBA-CELLS Synchrotron, in *Proc. ICALEPCS'17,* Barcelona, Spain, Oct. 2017. doi: 10.18429/JACoW-ICALEPCS2017-TUAPL04

[4] OHWR SPEC http://www.ohwr.org/projects/spec

[5] X. Serra, *et al.*, "A Generic Fpga Based Solution for Flexible Feedback Systems", *in Proc. PCaPAC'16*, Campinas, Brazil, Oct. 2016, paper FRFMPLCO06.