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BIOINGEGNERIA

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To the Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering at AGH, University of Science and Technology

Author: *Aleksandra Krzyzanowska*

Title: *Digitally-Assisted Analog Circuits for Hybrid Pixel X-ray Detectors*

University: *AGH, University of Science and Technology*

Reviewer: *Chiara Guazzoni, Associate Professor with Tenure, Politecnico di Milano and Research Associate, Istituto Nazionale di Fisica Nucleare (INFN)*

This document contains my personal, original and confidential review of the thesis of Aleksandra Krzyzanowska. I would like first to thank Aleksandra, her PhD Advisor, Grzegorz Deptuch and the Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering at AGH, University of Science and Technology for the opportunity to read and review this thesis that contains interesting original results in a field (X-ray imaging at synchrotrons) of high relevance and at the state-of-the art for the community. The document is organized as follows. After an introduction on the thesis content, I will present some general comments on the thesis organization and content. A section dedicated to some detailed amendments follows. The document ends with a global evaluation of the thesis.

General Comments:

The thesis describes the qualification and detailed theoretical analysis of a novel multichannel readout and processing circuit for hybrid pixels detectors intended for X-ray imaging. In particular the core of the thesis is the study, analysis and detailed qualification by means of simulations and experiments of the C8P1 algorithm as implemented in the Chase Jr. chip.

The thesis is well organized. After a comprehensive introduction on the basic concepts of X-ray interaction with matter, X-ray imaging and performance of a detection system based on hybrid pixel detectors together with the main limitations in the readout electronics, the thesis offers a review of the algorithms conceived to deal with charge sharing and of the implementation of one of them, the C8P1, in the Chase Jr. chip. The central part of the thesis is devoted to the simulation of the performance in presence of

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charge sharing phenomena of a generic detector readout channel at different levels of detail and complexity (static and dynamic models), to the development of the experimental setup and to the discussion of the results of the experimental qualification, carried out in the lab and more extensively with X-rays at the Advanced Photon Source of Argonne National Laboratory, where a prototype system underwent a series of dedicated qualification measurement. A comprehensive list of reference completes the thesis.
An interesting aspect of the thesis organization is the proposition at the beginning of the work of four theses, that - as the author says – contribute to better shape and motivate the research described in the thesis. Somehow the four thesis are the leit-motiv guiding the reader through the document.
The thesis contributes to the analysis methods of frontend circuits for X-ray imaging especially when dealing with charge sharing phenomena. The approach followed both for the analysis and for the experimental qualification is rigorous and data analysis is carried out appropriately.
The PhD candidate shows a solid understanding of the state-of-the-art in the field and the knowledge of the related current literature. Given the diversity of the work and the amount of results it is not always evident reading the thesis how to disentangle the personal contribute of the PhD candidate with respect to the contribution of the research group.

Detailed Amendments:

- *p. 38 when dealing with drift and diffusion also Coulomb repulsion should be considered since it starts to become relevant at moderately high energies (around 10 keV) or at high intensities as in the case of synchrotron light.*
- *p.40 the Gaussian charge cloud model is valid only in the case of free expansion and neglecting Coulomb repulsion.*
- *p. 45 probably ENC has to be defined independently from eq. 1.19 that is not completely correct since in presence of the detector it is not separated from the intrinsic statistical fluctuation.*
- *p. 49 when commenting Eq. 1.23 some nomenclature errors are present. ENC_i in the equation is the current white noise or parallel white noise, ENC_v is the white voltage noise or the white series noise. ENC_f is properly defined as the voltage flicker noise.*
- *p. 49 when commenting Eq. 1.26 you state that F_i, F_v and F_f "are the constants for the Semi-Gaussian shapers determined by the filter type" and then give the coefficients for the RC-CR filter. An RC-CR filter is not a semi-Gaussian filter. I would better state that those are coefficients that depend only on the filter output-pulse shape and then you can provide the coefficients for the shaping function you like better. Since you use the unilateral power spectral density (i.e. you consider only the physical frequency it is correct that F_i and F_v are equal to 0.924. On the contrary I disagree on the value of F_f that should be 0.59 and not 3.70.*
- *p. 57 the list of key terms could be moved to an appendix to ease readability.*

POLITECNICO
MILANO 1863

- *-p. 75 given that LabVIEW is not commonly used for Monte Carlo simulations it would be interesting to justify the choice of this software instead of others.*
- *-p. 75 against the choice of a pure Gaussian shape for the charge cloud see the comment to p. 40.*
- *-p. 78 – p. 82 the maps of the counts shown in Fig. 3.4 and 3.5 do not give a quantitative insight into the results, but just a qualitative description. A better insight is – for sure – given by the Q-parameter vs threshold plot.*
- *-p. 84 – p. 85 the surface plots of Fig. 3.7 and 3.8 provide an excellent qualitative view of the attribution of the number of counts to each pixel or of the number of extra counts or lost hits but does not allow a quantitative comparison between the SPC and the C8P1 modes.*
- *-p. 88 last line missing space between "the" and "comparators".*
- *-p. 91 the first time you use the acronym for "X-ray Photo Correlation Spectroscopy write also the name in words.*
- *-p. 93 when describing the additional features added in the prototype version to ease the experimental qualification, describe shortly what the added functionality helps to probe.*
- *-p.94 I hope that the CSA output is not directly shorted to ground in order to prevent excessive power dissipation and ground looping.*
- *-p. 96 how was chosen the sequence of steps in the trimming procedure? Do the trimming results depend on the order used for the trimming process, i.e. DC offset trimming and CSA gain trimming provide the same values if the CSA gain is trimmed before the DC offsets? Do the trimming procedures feature any degree of dependence among them?*
- *-p. 98 I guess that the legend in Fig. 4c is wrong (in the sense that the two entries have the color code exchanged) since the trimming procedure should lead to a reduction of the DC offset and not to an increase and the text states that the trimming procedure provided a 10fold reduction of the offset.*
- *-p. 98-99 relying only on the use of electrical injection for gain trimming is extremely risky since it asks for an excellent stability of the injection system and also an abwsolute reference for calibration is missing.*
- *-p. 99 the legend for the different colored lines in Fig. 4.6 is missing.*
- *-p. 100 it would be interesting a comment on the time stability of the trimming procedure. Is there any drift or dependence of the trimmed values on time, temperature, etc. that imposes to repeat the trimming procedure.*
- *-p. 101 I would change, at line 2, correction procedures with trimming procedures.*
- *-p. 101 The test bench here described is somehow relevant also for the trimming procedure. Is it the same that has been used. Could the chapter be moved before the trimming procedure section.*
- *-p. 110 when you state that the Chase Jr. module was tested with a sensor bonded you should specify the sensor type (material, thickness, pixel size, etc.)*
- *-p. 112 was the linearity of the trim DAC characteristic verified? How linear is it? Could you give some results on the linearity level (e.g. measured integral-non-linearity?)*

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- *-p. 115 Fig. 6.5 do not provide enough quantitative information. It is extremely difficult to spot the differences between Fig. 6.5a and Fig. 6.5b. Instead of the lines, would be more effective to show the fitted slopes as a function of the pixel number and the maximum computed INL for each fitted line.*
- *-p. 117 could you better explain how the mentioned 2.9% error was computed?*
- *-p. 119 Figg. 6.8 give a qualitative insight into the correct measuring of the counts before and after correction. However it is difficult to provide a quantitative understanding of the problem from the picture. Could it be possible to have a 1D plot (semilog y scale) of the registered number of counts as a function of the pixel number?*
- *-p. 121 Fig. 6.11 the same comment as for Fig. 3.7 and Fig. 3.8 at p. 84 – p. 85 holds.*
- *-p. 124 Could you provide details of the Rigaku X-ray generators(plural: more than one was used?), e.g. HV, max current, anode material (only Cu?).*
- *-p. 124 the energy provided by a Cu anode is 8.04 keV.*
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- *-p. 136 insert reference for each of the so-called hardware algorithms even if already cited before.*

<u>Global evaluation of the thesis:</u>

This thesis work contains the summary of a well-organized large amount of original work. The overall results are of scientific relevance to the community and well-presented and properly organized. The research results are at the level internationally required to earn a PhD, after positive defense. The dissertation is at the level required to earn a PhD with merit/distinction.

Milano, May 7th 2018

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