

ASIC for CPG Sensors with Grid-only Depth-of-Interaction Sensing

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Abstract -- A new version of the front-end Application Specific Integrated Circuit (ASIC) for Coplanar-Grid sensors is presented. Compared to the first version the ASIC is optimized for signal/noise performance, modified in peaking time, and it implements timing signals to measure the depth of interaction using the grids signals only. Experimental results using state-of-the-art CPG sensors and different approaches for reducing the error due to electron trapping are reported. A new technique that makes use of the sum and difference of the grids signals is also presented.

I. INTRODUCTION

The Coplanar-Grid (CPG) sensor is a compact and efficient solution for making large-volume room-temperature Gamma-ray spectrometers. It is being considered in applications ranging from nuclear material safeguard to radioisotope identification in security and defense, environmental remediation, well logging, medical diagnostics, and gamma-ray astronomy [1-4]. The availability of an Application Specific Integrated Circuit (ASIC) for CPG sensors is beneficial, especially in view of portable and battery operated detection systems.

By subtracting the signals from two co-planar grids the CPG is sensitive to electrons only, overcoming the limit of poor holes mobility. The electron trapping is typically compensated either with the relative gain technique [5] or by measuring the depth of interaction through the cathode signals [6].

The ASIC here proposed provides amplification of grids, difference and cathode signals, adjustable relative gain, high order filtering with output baseline stabilization, and timing signals. It allows measurement of all signals of interest and electron trapping compensation using both techniques. A first version of the ASIC was presented in [7]. The new version here presented differs with respect to the previous in three aspects. First, the front-end is optimized for resolution making use of the noise analysis results from the previous work. Second, the peaking time, originally 5 μ s, is now adjustable between 1.2 μ s and 2.4 μ s. Third, grids only timing signals

allow compensation for the electron trapping without cathode signal [7].

In this summary Section II describes the new architecture with some details on the front-end optimization, and Section III reports some experimental results. In Section IV a new technique is proposed for the measurement of the depth of interaction through the amplitude of the grids sum and difference signals only.

II. ASIC ARCHITECTURE AND RESULTS

In Fig. 1 the block diagram of the ASIC architecture is shown. It implements three front-end channels, two for the grids signals and one for the cathode signal. This architecture, which may appear very similar to the one reported in [7], implements three major changes.

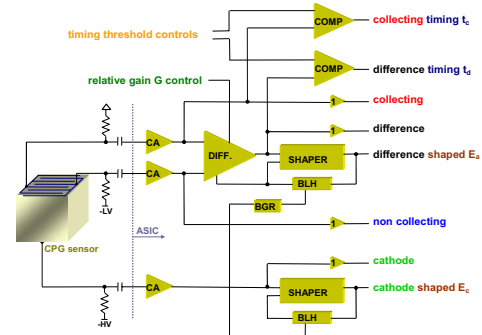


Fig. 1. Block diagram illustrating the ASIC architecture.

The first improvement consists of a re-design of the front-end stages by replacing the n-channel input device with a p-channel device. The noise analysis and experimental results in [7] demonstrated that, due to the correlation associated with the inter-grid capacitance, the series input noise from the front-end can severely limit the resolution of the system. The series noise, dominated by the low-frequency component, can be appreciably reduced if a p-channel device is used [8]. This change also required a re-arrangement of the dual-stage charge gain configurations, by appropriately inverting the two stages [7].

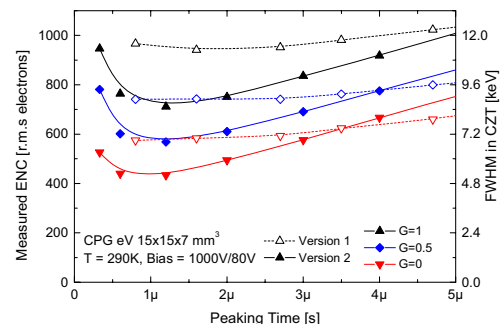


Fig. 2. Measured ENC versus peaking time for different values of the relative gain G with the CPG sensor connected and biased (solid symbols). The results from the old version are also reported for comparison (open symbols).

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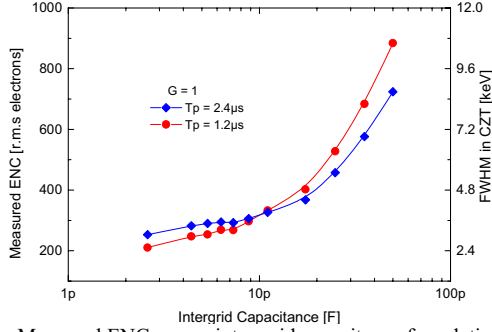


Fig. 3. Measured ENC versus inter-grid capacitance for relative gain $G=1$ and the two values of peaking time.

The second improvement consists of decreasing the peaking time from the original $5\mu\text{s}$ value, having it selectable between $1.2\mu\text{s}$ and $2.4\mu\text{s}$. This change makes the ASIC suitable for use with larger CPG sensors, typically characterized by higher leakage currents. In Fig. 2 the measured ENC versus the peaking time for different values of the relative gain G are shown. For comparison the measurement from the previous ASIC version is also reported [7]. The measurement was made by using the ASIC output from the first, real pole of the shaper, followed by a suitable combination of differentiation and integration with the Ortec 450 research amplifier. The increase in parallel noise observed at longer peaking times is partially due to the noise contribution from the real pole stage of the shaper in the ASIC (set at 360ns and optimized for the $1.2\mu\text{s}$ peaking time) and partially due to the different noise weighting function (lower order [8]). The improvement in resolution at the peaking times of interest ($1.2\mu\text{s}$ and $2.4\mu\text{s}$) can be observed. For values of relative gain $G \approx 1$ the FWHM for this sensor is reduced from 11.5keV to 8.4keV , corresponding to about a factor 2 in power. In Fig. 3 the measured ENC of the ASIC versus the inter-grid capacitance for relative gain $G=1$ and the two values of peaking time is shown.

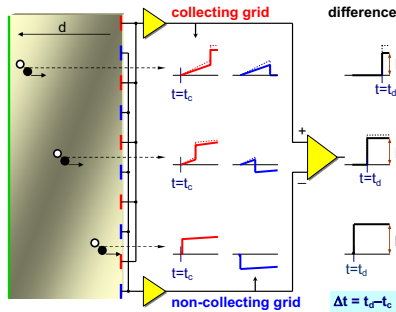


Fig. 4. Schematic of the concept of measuring the depth of interaction from the timing delay Δt between the collecting signal timing t_c and the difference signal timing t_d .

The third improvement consists of measuring the timing of the collecting signal in place of the one of the cathode signal. The timing delay $\Delta t = t_d - t_c$ from the collecting signal to the difference signal is a measure of the depth of interaction (see Fig. 4). The error due to the threshold, positioned a value V_{th} above the baseline of the signal, can be corrected with $\Delta t_{eff} \approx \Delta t + 0.5 \Delta t_{max} V_{th} / E_d$ where Δt_{max} is the maximum transit time for the electrons, E_d is the amplitude of the difference signal for the specific event, and 0.5 takes into account the

partial induction due to a single grid. The depth of interaction d can be calculated as $d \approx d_{max} \Delta t_{eff} / \Delta t_{max}$. This concept, already introduced in [7], allows the measurement of the depth of interaction by using the grids signals only (collecting and difference). The bi-parametric data (energy E_d and depth d for each event) can be used to correct for the electron trapping.

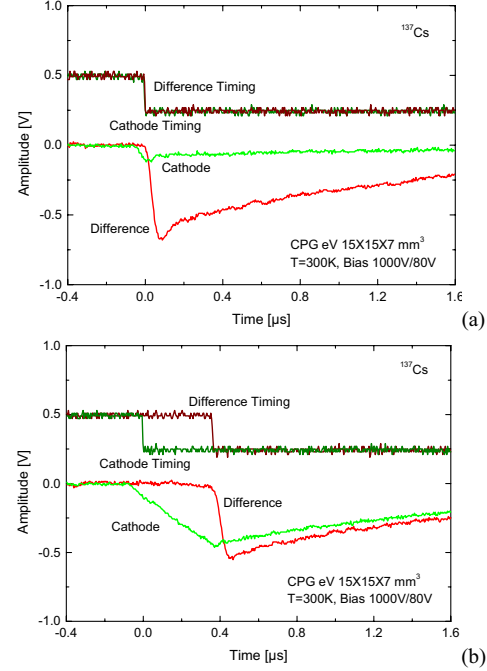


Fig. 5. Measured unshaped and timing responses from the ASIC-CPG system to ^{137}Cs signals for an interaction (a) close to grid and (b) close to cathode.

This technique has some advantages compared to the two known techniques. With respect to the relative gain approach it doesn't require hardware adjustments to adapt the compensation and can be applied either in real time or after the acquisition. With respect to the cathode/difference ratio correction technique it doesn't require the additional cathode amplification and processing with advantages in terms of power and area, especially considering the need for bulky capacitors for the coupling of the high-voltage cathode to the ASIC.

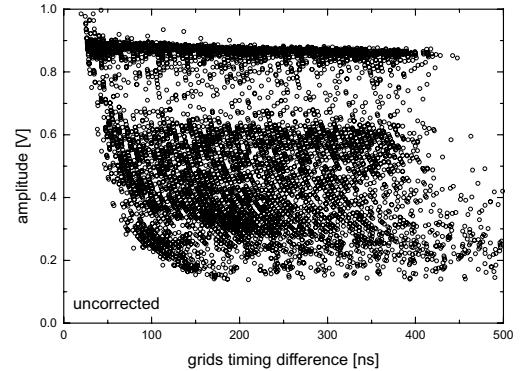


Fig. 6. Bi-parametric spectrum from ^{137}Cs measured using the grids timing difference, which is directly related to the depth of interaction.

Shown in Figs. 5 are the unshaped and timing responses of the ASIC-CPG system to ^{137}Cs signals for (a) an interaction close to grid where the timing delay is small and (b) an inter-

action close to cathode where the timing delay is large. In Fig. 6 the bi-parametric spectrum (energy E_d versus depth d for each event) from ^{137}Cs signals, corrected for the error due to the threshold, is shown. In this measurement the relative gain G was set to 1 and the trapping effect on the 662keV line (amplitude average decreasing from 0.89V to 0.86V from grids to cathode) can be observed. The correction for electron trapping depends on the depth of interaction and, once extracted from this measurement, it can be applied to following measurements on each event in real time. If a linear correction is used, a result comparable to the relative gain compensation technique should be expected.

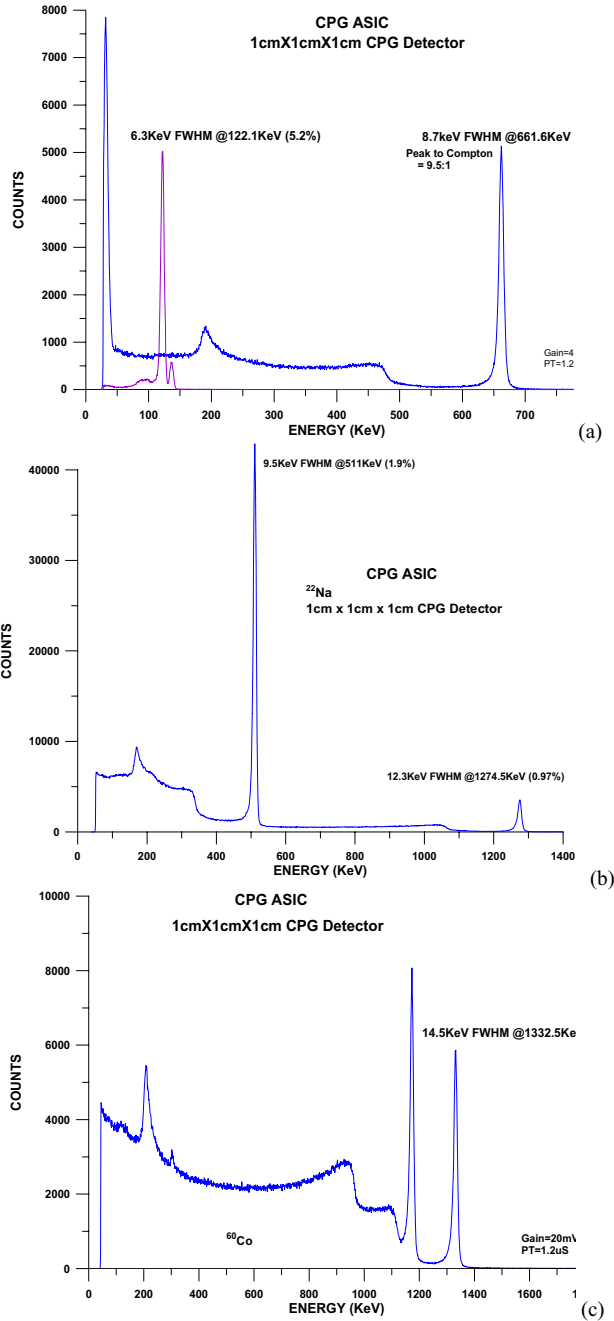


Fig. 7. Spectral measurements from ^{57}Co and ^{137}Cs (a), ^{22}Na (b), and ^{60}Co (c) sources with a 1mm $\times$ 1mm $\times$ 1mm CPG sensor.

III. SPECTRAL MEASUREMENTS

The ASIC-CPG system was characterized using the relative gain compensation technique and the depth of interaction correction technique. In the first case the measurements were done at eV Products using state-of-the-art CPG sensors. In the second case the measurements were done in Brookhaven National Laboratory with the same sensors used to characterize the previous version of the ASIC, and the acquisition chain included the PDD ASIC [9], a custom acquisition board and LabView [10] environment.

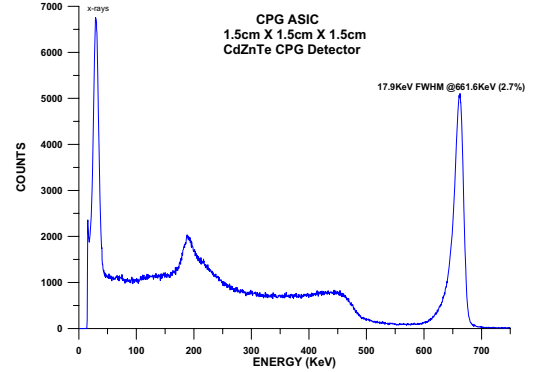


Fig. 8. Spectral measurements from a ^{137}Cs source with a 1.5cm $\times$ 1.5cm $\times$ 1.5cm CPG sensor.

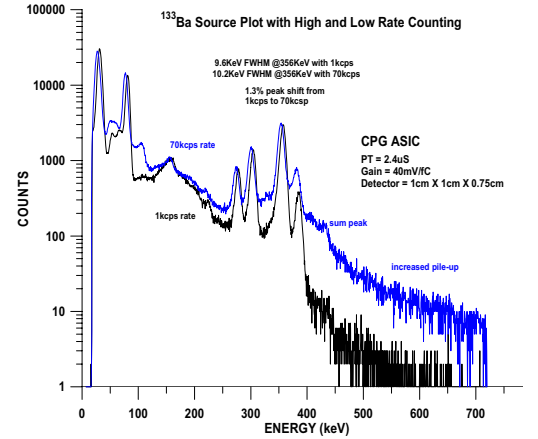


Fig. 9. Spectral measurements from a ^{133}Ba source with a 1cm $\times$ 1cm $\times$ 0.75cm CPG sensor.

A. Relative Gain Compensation Technique

All measurements here reported were done at temperature $T \approx 23^\circ\text{C}$ and using sources without collimator. In Figs. 7 the spectra from ^{57}Co and ^{137}Cs (a), ^{22}Na (b), and ^{60}Co (c) are shown with a 1cm $\times$ 1cm $\times$ 1cm CPG sensor.

In Fig. 8 the spectrum from a ^{137}Cs source with a 1.5cm $\times$ 1.5cm $\times$ 1.5cm CPG sensor is shown. The ASIC-CPG system was also tested for high rate. In Fig. 9 the spectra from a ^{133}Ba source with a 1cm $\times$ 1cm $\times$ 0.75cm CPG sensor at 1kcps and 70kcps rates are shown. Some deterioration of the spectrum due to the pile-up is observed.

B. Depth of Interaction Correction Technique

All measurements here reported were done at temperature $T \approx 27^\circ\text{C}$ and using a ^{137}Cs source without collimator. In Fig. 9 measurements using the cathode/difference ratio are shown.

The depth of interaction was calculated from a simple linear approximation, and the second order errors described in [11] were not included. The gain coefficient for the correction was calculated from the position of the 662keV peak at each depth.

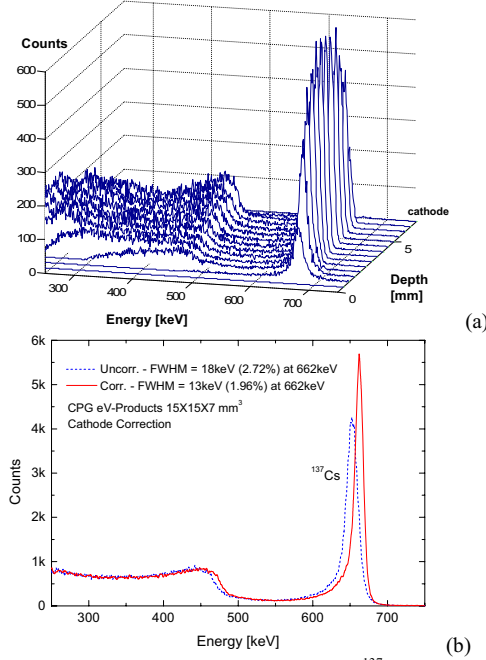


Fig. 9. Spectral measurements from a ^{137}Cs source with a $1.5\text{cm} \times 1.5\text{cm} \times 0.7\text{cm}$ CPG sensor. The 662keV peaks for the spectra at different depths in (a), calculated from the cathode/difference ratio, were used to correct the cumulative spectrum in (b) increasing the resolution from 18keV (uncorrected) to 13keV (corrected).

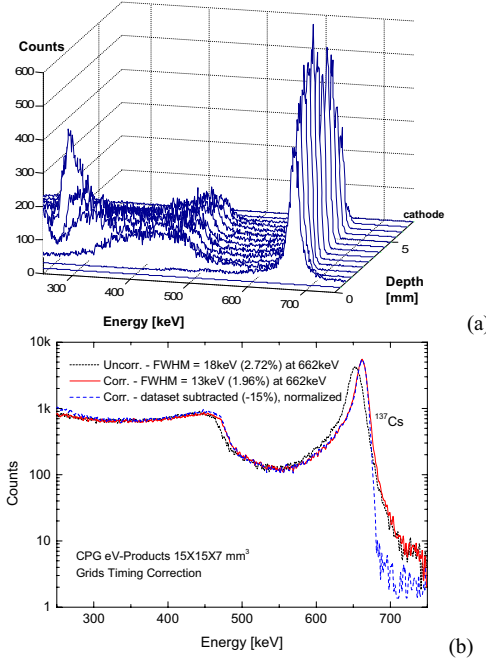


Fig. 10. Spectral measurements from a ^{137}Cs source with a $1.5\text{cm} \times 1.5\text{cm} \times 0.7\text{cm}$ CPG sensor. The 662keV peaks for the spectra at different depths in (a), calculated using the grids timing difference, were used to correct the cumulative spectra in (b) increasing the resolution from 18keV (uncorrected) to 13keV (corrected). The spectrum with two datasets removed and normalized is also shown.

In Fig. 10 corresponding measurements using the grids timing difference are shown. The difference at low energy between the spectra at different depths in both techniques is partially due to threshold effects and result in some low-energy events attributed to a wrong depth. Further investigation of these aspects is needed. However, since the cumulative spectrum is eventually used, the impact on the overall process is small. In Fig. 10b the spectrum where the first two datasets from the grids were removed is also shown, renormalized to the full corrected spectrum. In front of a $\approx 15\%$ loss in counts, an improvement in the spectral performance on the right side of the 662keV spectral line can be observed. The worsening of the spectral response at the right side of the 662keV spectral line for event close to the grids was already observed and discussed in [6].

IV. SUM OF GRIDS SIGNALS FOR DEPTH CORRECTION

The sum of collecting and non-collecting signals is an alternative approach to grids-only measurement of the depth of interaction.

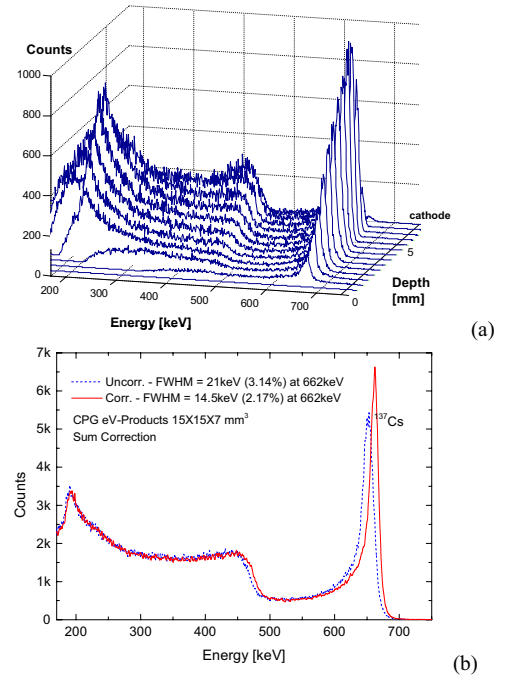


Fig. 11. Spectral measurements from a ^{137}Cs source with a $1.5\text{cm} \times 1.5\text{cm} \times 0.7\text{cm}$ CPG sensor. The 662keV peaks for the spectra at different depths in (a), calculated using the sum of collecting and non-collecting signals, were used to correct the cumulative spectra in (b) increasing the resolution from 21keV (uncorrected) to 14.5keV (corrected).

As reported in [12,13] the sum of the two signals is, to a first order, equal to the cathode signal (some differences may be observed for the presence of guard rings). A noise analysis similar to the one reported in [7] shows that noise on the sum of the two signals is not affected by the correlation due to the inter-grid capacitance. Compared to the use of the non-collecting signal, the sum has also the advantage of strongly reducing the dependence of the response on the position of the event with respect to the strips. This dependence is relevant for events close to the grids. In Fig. 11 measure-

ments using the sum/difference ratio are shown. The collecting and non-collecting signals from the ASIC were summed using the Ortec 433A summing amplifier and shaped using the Ortec 450 research amplifier. A detector exhibiting worse spectral performance compared to the one used in previous measurements was used in this case. The depth of interaction was again calculated from a simple linear approximation, and further investigation of second order errors is needed. The correction process was carried out as in previous cases extracting the gain coefficient from the position of the 662keV peak at each depth.

V. CONCLUSION

An Application Specific Integrated Circuit (ASIC) for Coplanar-Grid (CPG) sensors was presented. Compared to the previous version, this ASIC has improved electronics resolution and implements the signals for the measurement of the depth of interaction using grids signals only. The ASIC was characterized with CPG sensors, correcting for electron trapping using the relative gain compensation technique and the depth of interaction correction technique. The sum of the collecting and non-collecting signals is also proposed as alternative to the timing signals for a depth correction based on grids signals only.

VI. ACKNOWLEDGMENT

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