Pixel readout electronics development for an imaging silicon pixel array gamma camera with on-chip energy discrimination system.

Valentino Cencelli[1], *Francesco de Notaristefani*[1], *Carmelo D'Ambrosio*[2], *Gianlorenzo Masini*[3], *Lorenzo Colace*[3].
[1]*INFN, Sezione di Roma III, Via della Vasca Navale, 84 00146 Roma, ITALY*
[2]*CERN, EP Division, CH 1211 Genava 23, Switzerland*
[3]*Dipartimento di Ingegneria Elettronica, Università di Roma 3, Via della Vasca Navale, 84 00146 Roma, ITALY*

1 Introduction

In recent years we have demonstrated an Imaging Silicon Pixel Array (ISPA) gamma camera based on the Omega-3 chip developed at CERN [1] [2] [3]. This device could take advantage of the Omega-3 chip, but was limited by the nature of the readout electronics, specifically designed for high-energy physics experiments. In this paper we present the development of a readout electronic chip designed to meet the specific requirements of nuclear medicine.

In fact the characteristics of the source in the two cases are very different: in High Energy Physics experiments the source has usually a very high rate, in the megahertz range, and is synchronised with a beam clock at a fixed rate. The clock is available to the designer, who can use it to drive the readout system, and data selection is achieved using different levels of triggers with different time response, which determine the meaningful events. Moreover, the readout electronics is usually inserted in huge detectors with millions of channels and many constraints due to material budget, power consumption and radiation hardness, have to be taken into account.

In nuclear medicine, vice versa, a radiopharmaceutical tracer, i.e. a sugar marked with meta-stable radioactive atoms like TC^{99met}, is injected in the blood flow in proximity of the area under study. Cells in such area absorb the sugar with intensity proportional to the metabolic activity of tissues, giving rise to a concentration of the radiopharmaceutical tracer proportional to such activity. Therefore, the particle flow is asynchronous, being generated by natural decay of the radiopharmaceutical tracer, and a large background is present due to natural radioactivity, cosmic rays and Compton emission from other organs. Moreover, the radioactivity dose must be kept as low as possible. This takes the overall counting rate in the range of hundreds of kilohertz, while the signal stays well below $1kHz$. This condition makes energy discrimination very important, in order to save, in the gamma image, the information related to the metabolic activity that is the most meaningful. The system must be also as compact as possible to be easily moved and exploited. Contrary to high-energy physics applications, power consumption and radiation hardness are usually not an issue.

In this contribution we present a novel IC-chip designed to match such requirements: in its final version the chip will consist of an array of 96 by 96 pixel cells, 150μ by 150μ. At present time a test chip is being assembled with a matrix of 32 by 32 pixel cells. The pixel cell is equipped with a Charge Sensitive Amplifier (CSA), a shaper and a discriminator, leakage compensation system, a 3 bit threshold adjustment DAC, and a test circuit. In the perifery there are voltage and current DAC's to provide biasing and the I/O devices. Peculiar to this IC is the on-chip energy discrimination system: the pulse output of the shaper is converted into current and then summed up using the Kirckhoff current law, in the chip perifery an array of current buffers sends the current, proportional to the global amount of charge collected by the pixel matrix, to three threshold discriminators that drive the trigger logic.

In Section 1 we will summarize how the ISPA tube based on the Omega-3 chip currently works; in Section 2 an overall description of the chip is presented (named Γ_0); in Section 3 details are given about the front end and on-chip energy discrimination system. Finally, in the last Section we will draw conclusions and future perspectives.

2 ISPA system based on Omega 3

In Figure 1 we show a schematic representation of the ISPA system that is actually working in our laboratory at CERN. The system is composed by a vacuum tube with a YAP crystal window. A photocatode is deposed on the inner side of the window and the Omega 3 chip acts as the position sensitive device, its potential is the same as the anode in the high voltage circuit. When a gamma photon with energy in the range of interest, a typical value is 140 KeV (TC^{99met}), hits the crystal, about 2 to 5 hundred photoelectrons are generated. The photoelectrons are then accelerated trough a 20 kV potential and hit the photodiode matrix generating 5700 electron hole pairs each. Experimental data show that, with the current geometry, the photoelectron spot is about one mm in diameter.

As schematically indicated in Figure 1, while electrons are collected by the readout electronics, forming the photoelectron spot image, holes are collected on the top side of the detector matrix (that has a common contact area), and generate a current sent to the external energy discrimination system. This system is composed by a CSA, a shaper circuit and a Double Threshold Discriminator (DTD). The signal of the DTD is used to trigger the driver system and to start the matrix download process. Usually

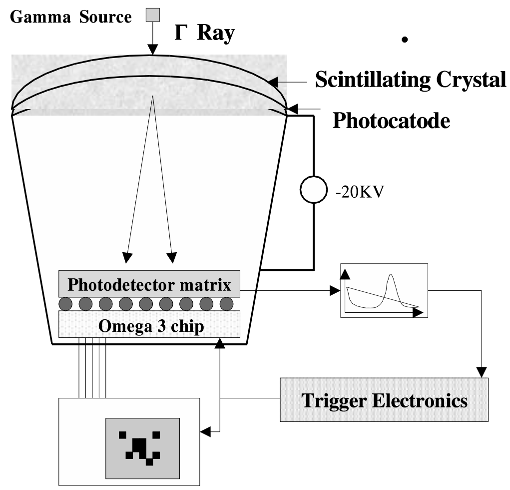

Figure 1: ISPA schematic representation.

a multi channel analyzer is also connected for calibration purpose.

3 The Γ_0 IC-chip structure

The chip will be realized in a commercial 0.25μ technology, this offers both the density of components needed to implement sufficient intelligence in the pixels and 5 level of metals needed to deliver supply and make bus interconnection. The power supply voltage will be set at the standard for this technology i. e. 2.5V.

In Figure 2, a block diagram of our chip is depicted. Two main region are distinguishable: a pixel matrix, formed by nine blocks 32 by 32 elements and a periphery.

A32 bit I/O data bus connects each of the cells in this 32 by 32 pixel block; each pixel is equipped with a 6 bit configuration register.

The perifery contains all the decoding logic, a set of voltage and current DAC's to bias the front-end circuitry and a set of current DAC's to set the pixel and the global energy discrimination system thresholds. An energy discrimination cell is also present which will be described in more details in Section 4.

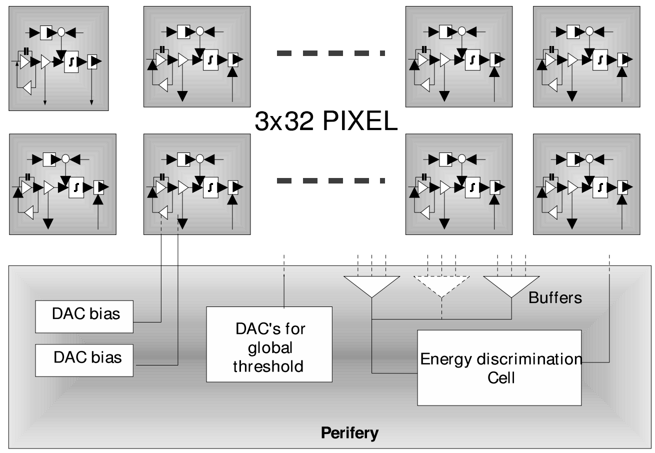

Figure 2: Chip block diagram.

4 Front End and Energy discrimination System

The pixel cell is divided into an analog and a digital part. The digital part is made by a set of flip flops arranged in a fifo buffer, driven by the energy disciminatoin system. The analog part is composed by a front-end amplifier, with leakage compensation system, followed by a shaper stage, with a peaking time of $100ns$, both these blocks are differential in order to minimize the effect of the substrate coupling during the switching of the digital part. The front end is a folded cascode amplifier with a leakage compensation system made by the typical structure described in the work of Krummenacher [7]. A test input can be applied to the front end switching a voltage step through a capacitor. The amplitude of the step is determined by two analog references external to the chip. The shaper, whose schematic is shown in Figure 3.b, has the double function of shaping the input voltage pulse, with a peaking time of $\tau_s = C_l\, g_{mi} = C_h\, g_{mo}$, and converte it to a current, eventually copied trough transistor M1 and M2. The high capacitance of the mirror does not affect the shaping time being hidden by the M3, M4 cascode stage, whose g_m actually determines the time constant. Current output is sent locally to a discriminator, whose threshold could be finely adjusted by an on-pixel 3bit current DAC. The local discriminator determines if at least one photoelectron has hit the pixel. A copy of the current output is summed using the Kirchoff current law into a node connected to a column buffer, whose schematic is shown in Figure 3.a.

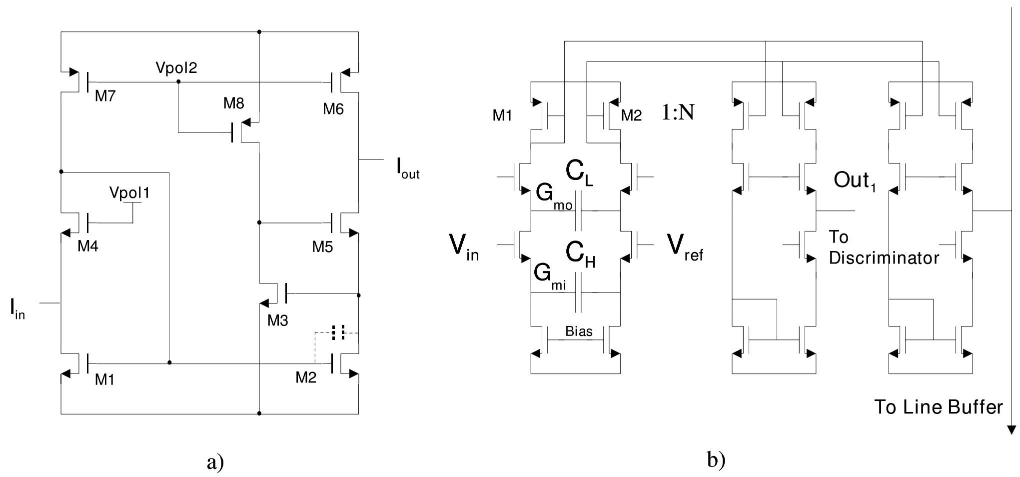

Figure 3: Column buffer circuit a), Shaper circuit b).

This circuit topology was developed at CERN and used for the fast-multiplicity subsystem of the Alice1LHCb chip [4], [5], [6].

The main problem found in designing such circuits is that the metal line connecting all the pixel outputs goes trough the entire chip, giving rise to a huge, i.e. in the pF range, line capacitance. Of course the pole that this capacitance forms with the line buffer input impedance must not dominate the behavior of the system. For this reason a very fast circuit with a very low input impedance is needed. Moreover the circuit must be linear in a wide range to cope with the possibility that a high number of pixels is hit. The circuit in Figure 3.a, exploiting the feed-back properties, meets these requirements. In fact, on the input side, only a fraction of the current, equal to $1/(1+r_{o7}\, g_{m1})$, goes trough M4, this sets the dominant pole due to the line capacitance to $C_{line}\, g_{m4}(1 + r_{o7}\, g_{m1})$, that can be easily made non-dominant. On the output side, when the current rises at the input M4 remains in the same biasing conditions, while through M5, that is needed in order to avoid the Miller effect at the output on C_m, flows all the output current. If the bias of M5 is fixed like the one of M4, M2 rapidly goes out of saturation. The output feed-back loop avoids this effect holding the drain voltage of M2 to a more constant value.

5 Conclusion

In this paper we described the design of a pixel chip that was developed for gamma ray imaging in medical application. The chip was designed in a commercial $0.25\mu m$ technology and will be able to self trigger on the gamma event. A first 32x32 pixels prototype will be sent to foundry for the first MPW run in 2003, and will be used to check the functionality of the designed block. The final 96x96 version pixels will be made after the test results in the late 2003.

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