Ultimate Sensor

Analog Part

(Preliminary version)

Designers: G. Bertolone, C. Colledani, A. Dorokhov, W. Dulinski, G. Dozière, A. Himmi, Ch. Hu-Guo, F. Morel, H. Pham, I. Valin, J. Wang
Test engineers: G. Claus, M. Gelin, M. Goffe, K. Jaaskelainen, M. Specht
Institut Pluridisciplinaire Hubert Curien IN2P3-CNRS / UdS Strasbourg – France

Document history		
Version	Date	Description
1.0	November 2010	Ultimate design review: Analog Part

This document describes the functional blocks of the analog part of the sensor following the scheme in 4 parts:

I - Optimization of pixel design -

II - Optimization of discriminator design -

III - Auxilliary functional blocks -

IV - Optional blocks -

The characteristics of the Ultimate sensor adapted to the STAR requirements are summarized in the table below.

In the Pixel Vertex Detector at STAR	Sensors requirements
Sufficient resolution to resolve the secondary decay vertices from the primary vertex	Sensor spatial resolution < 10 µm
Multiple scattering minimisation X/X_0 = 0.37 % per layer	Sensors thinned to 50 µm, mounted on a flex kapton, aluminium cable
Luminosity = 8 10^{27} /cm^2 /s at RHICII	~ 200-300 hits/sensor (~ 4 cm^2) in the integration time window (~ < 200 µs)
Low mass in the sensitive area of the detector => airflow based system cooling	Sensor work at ambient temperature (~ 30°C) Power dissipation ~ < 170 mW /cm^2 Target ~100 mW /cm^2
Sensors positioned close to the interaction region (2.5 – 8 cm radii)	Radiation environment: ~ 150 kRad /year, few 10^{12} N_{eq} /cm^2 /year

Table 1

The Ultimate sensor design is based on the MIMOSA-26 sensor architecture developed for the EUDET beam telescope and it benefit from the test results of this sensor. Many features of the MIMOSA-26 sensor will be incorporate in the Ultimate sensor. Nevertheless, as shown in the table 2 showing the main characteristics and performances of the MIMOSA-26 sensor, it necessitates optimizing the design of Ultimate in order to satisfy the performance requirements at STAR.

Optimization of the MIMOSA-26 sensor toward Ultimate

The first objective is the reduction of the power dissipation. The power supply voltage of the chip will be reduced from 3.3 to 3 V. The pixel pitch has been enlarged from 18.4 µm to 20.7 µm to reduce the power dissipation (of ~ 15 %). The integration time is then ~< 200 µs. This is a trade-off between the power consumption and the non-ionizing radiation tolerance.

The second objective is to improve the radiation tolerance. The radiation tolerance can be improved by using a high resistivity EPI substrate to improve the charge collection efficiency and time and by a radiation tolerant pixel design. The pixel design has been validated by a medium prototype MIMOSA22-AHR submitted in April 2010. The table 3 presents the test results of the chip for the pixel (S7) which will be integrated in the Ultimate sensor.

An on-chip voltage regulator has been implemented in this prototype to provide the pixel clamping voltage. In this way, interferences on this critical node could be minimized. The value of the pixel clamping voltage could be adjustable by an internal DAC.

The timing diagram for discriminators has been as well optimized in order to reduce the threshold inhomogeneity seen in the PHASE-1 and MIMOSA-26 sensors tests.

The discriminator outputs are connected to a zero suppression circuit (SuZe) adapted to the STAR condition. As the hit density is higher than EUDET, larger memories are implemented (3.5 times larger than MIMOSA-26). These memories are IP SRAM of 2048x32 bits provide by the AMS foundry.

The binary output data are sent out at higher frequency from 80 MHz to 160 MHz.

Testing functionalities all along the readout path have been implemented in the MIMOSA-26 sensor and now enhanced in the Ultimate sensor.

Description of the Ultimate sensor

The functional block of Ultimate sensor is presented in the figure 1.

The Ultimate sensor includes a pixel array of 928 rows and 960 columns with 20.7 µm square pixels, having a sensitive area of ~ 3.8 cm^2 similar to that of the PHASE-1 sensor. It incorporates the amplification and CDS inside each pixel, column-level discriminators followed by a zero-suppression circuit and two output memories. All columns are readout in parallel in the rolling shutter mode at 5 MHz (200 ns/row). The sensor integration time is 185.6 µs. There are two LVDS outputs to send out the sparsified data at 160 MHz.

The on-chip programmable bias DACs, voltage references, test mode selection are set via a JTAG controller.

A PLL and a voltage regulator intended to provide the analog power supply from the digital power supply are implemented as individual test blocks (with their own padring). These blocks are optional.

The characteristics and extrapolated performances of the Ultimate sensor are presented below (Table 4).

MIMOSA-26 characteristics	MIMOSA-26 performances
Pixel array: 576 rows x 1152 columns, Pixel pitch: 18.4 µm Sensitive area ~ 2 cm^2	Temporal Noise : 0.75 – 0.85 mV Fixed Pattern Noise : 0.3 – 0.4 mV ENC ~ 13 -14 e-
~ 5 hits/sensor	Efficiency ~ 99.5 % for fake hit rate 10^{-4}/ pixel
Subtrate: Standard EPI layer	Spatial resolution ~ < 4 µm
Sensor work at temperature ~ 20°C Light power consumption constraints	Power consumption ~ 170 mW / cm^2
No constraint on radiation tolerance	Yield for functional sensors ~ 90 %

Table 2: main characteristics and performances of the MIMOSA-26 sensor

MIMOSA-22-AHR	MIMOSA-22-AHR performances (S7 pixel design)	Non-irradiated T= 15°C	Irradiated In STAR conditions*
Pixel array: 576 rows x 128 columns Pixel pitch: 20.7 µm	Binary Temporal Noise : Binary Fixed Pattern Noise : ENC ~	0.8 – 0.9 mV 0.2 – 0.3 mV 13–14 e-	1 - 1.1 mV 0.2 – 0.3 mV 17-18 e-
Readout freq.: 100 MHz (160 ns/row)	Efficiency ~	99.9 % for fake 10^{-5}/pixel/evt	99.9 % for fake 10^{-5}/pixel/evt
Various pixel design	Spatial resolution ~	3.5 µm	3.5 µm
Subtrate: HR 15 µm			

Table 3: main characteristics and performances of the MIMOSA-22-AHR sensor
*STAR conditions: 30°C, 150 kRad, 3 10^{12} N_{eq} /cm^2

Ultimate characteristics	Expected Ultimate performances
Pixel array: 928 rows x 960 columns Pixel pitch: 20.7 µm Sensitive area: ~ 4 cm^2	Temporal Noise: ~ (mainly coming from the pixel) Fixed pattern noise: ~ < 0.4 mV (reduced discri inhomogeneity)
Suze condition: ~ 200-300 hits/sensor	Sensor spatial resolution: ~ 4 µm
Radiation tolerant pixel design	Voltage supply: 3 V
	Power consumption: ~ 130 mW/cm^2

Table 4: main characteristics and expected performances of the Ultimate sensor

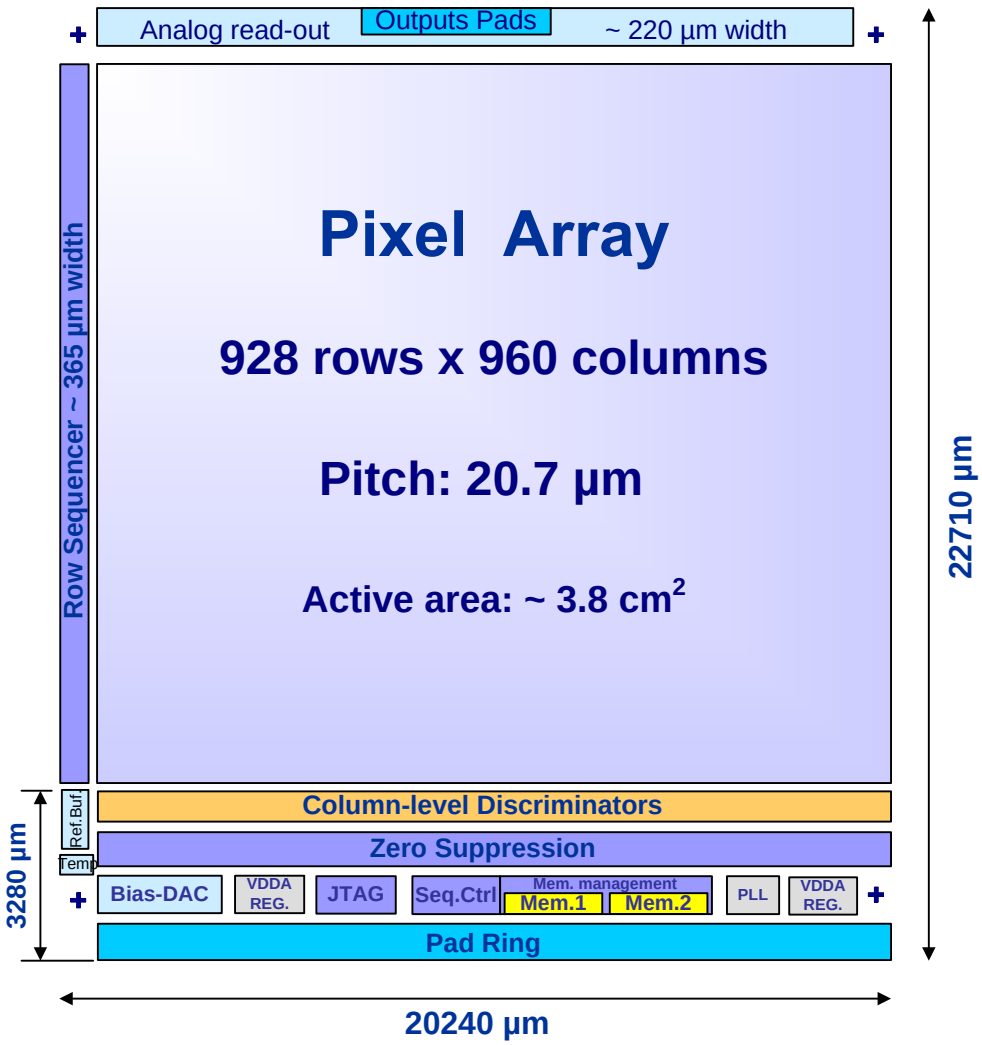

Figure 1: Ultimate sensor functional blocks