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Noise Occupancy in Single Channels and Adjacent Channel Coincidences in the Binary Read-out Systems for Silicon Detectors

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ABSTRACT

We have measured the noise rate of a binary read-out system for silicon microstrip detectors, i.e. a system characterized by one threshold. We determine the noise occupancy of a single channel and of the coincidence of two adjacent channels as a function of the threshold. We find that the coincidence occupancy approximates three times the square of the single channel occupancy at the same threshold. For the ATLAS-style silicon detectors with measured noise sigma of 0.275fC, the coincidence occupancy at 0.5fC is 16 times larger than the single channel occupancy at 1fC. This has obvious consequences for schemes utilizing coincidences of adjacent channels with lowered threshold.

INTRODUCTION

One of the options for the read-out of the ATLAS Silicon strip detector system SCT is the so-called binary system [1-2], where the pulse height is discriminated on-chip with a common threshold and only the addresses of channels with pulse height exceeding this threshold are recorded. This system has proven high efficiency and low noise occupancy at a threshold equaling a quarter of the most likely charge deposited by minimum ionizing particles and four times the noise sigma[3-4].

An interesting variation, to improve the efficiency and position resolution for "floating strips" [5], is to have not only one common threshold of about 1fC, but to have in addition a common threshold of 0.5fC with the requirement to record the channel only if two adjacent channels exceed this threshold in coincidence. This would obviously improve the efficiency in cases where the charge is shared between two channels. The question is if such a system can match or even lower the noise occupancy of the single threshold system.

NOISE OCCUPANCY MEASUREMENTS

We have determined the noise occupancy in a binary front-end system with 256 strips connected to a fast, low-noise read-out system. The bipolar amplifier-comparator chips LBIC [6] with 22ns shaping time are followed by a CMOS digital pipeline CDP128 [7]. By varying the threshold, the noise performance of the system can be studied. The noise occupancy is the average number of noise hits per channel per time slice of 25ns. The noise sigma σ can be determined from a plot of the occupancy O as function of threshold by performing a fit with a complementary error function [8]:

$$O(thr) = O_o \left[1 - \mathrm{erf}(thr/\sigma) \right] \qquad (1)$$

where $O_o = 0.35$ and $\sigma = 0.275\,\mathrm{fC}$ ($1720e^-$) for this particular detector (see below). For large threshold-to-noise ratio’s, this function is well approximated by a Gaussian [9].

In a similar manner, we can find the noise occupancy of two channels firing in the same time slice.

COINCIDENCE NOISE OCCUPANCY RATES

Assuming that the noise rates in adjacent channels are uncorrelated, we expect that the noise occupancy of adjacent channel coincidences O_{Coinc} is proportional to the square of the single channel occupancy of Eq. 1:

$$O_{Coinc}(thr) = O(thr)^2 \qquad . \qquad (2)$$

We made a measurement to check this assumption, by recording during threshold scans the coincidence rate of adjacent noise hits, simultaneously with single channel noise hits. This eliminates possible systematic errors due to uncertainty in the threshold setting and the amplifier noise sigma because they are common to both the single channel and the coincidence occupancy.

Fig. 1 shows the occupancy for single channels and it's square (Eq. 2), and the occupancy for coincidences of two channels with identical threshold. In one case, we recorded adjacent channels firing, in the other case we recorded coincidences of channels which are 10 channel numbers removed ("Non-adjacent channels"). In addition, we show an approximation to the coincidence data with an error function motivated by Eq. 1 with a noise sigma of $0.2 \approx 0.275/\sqrt{2}$ and a normalization 0.35^2. Several conclusions can be drawn from the data:

i) adjacent and non-adjacent channels show the same occupancy, indicating that neighboring channels are as well isolated as far removed ones.

ii) the error function fit describes the data well in the region of interest of thresholds around 0.5fC.

iii) the naive expectation of Eq. 2 that the coincidence occupancy is equal to the square of the single occupancy is wrong, it is more like three times that at threshold above 0.5fC. Thus we replace Eq.2 with the correct coincidence occupancy:

$$O_{Coinc,correct}(thr) = 3*O(thr)^2 \qquad . \qquad (2)$$

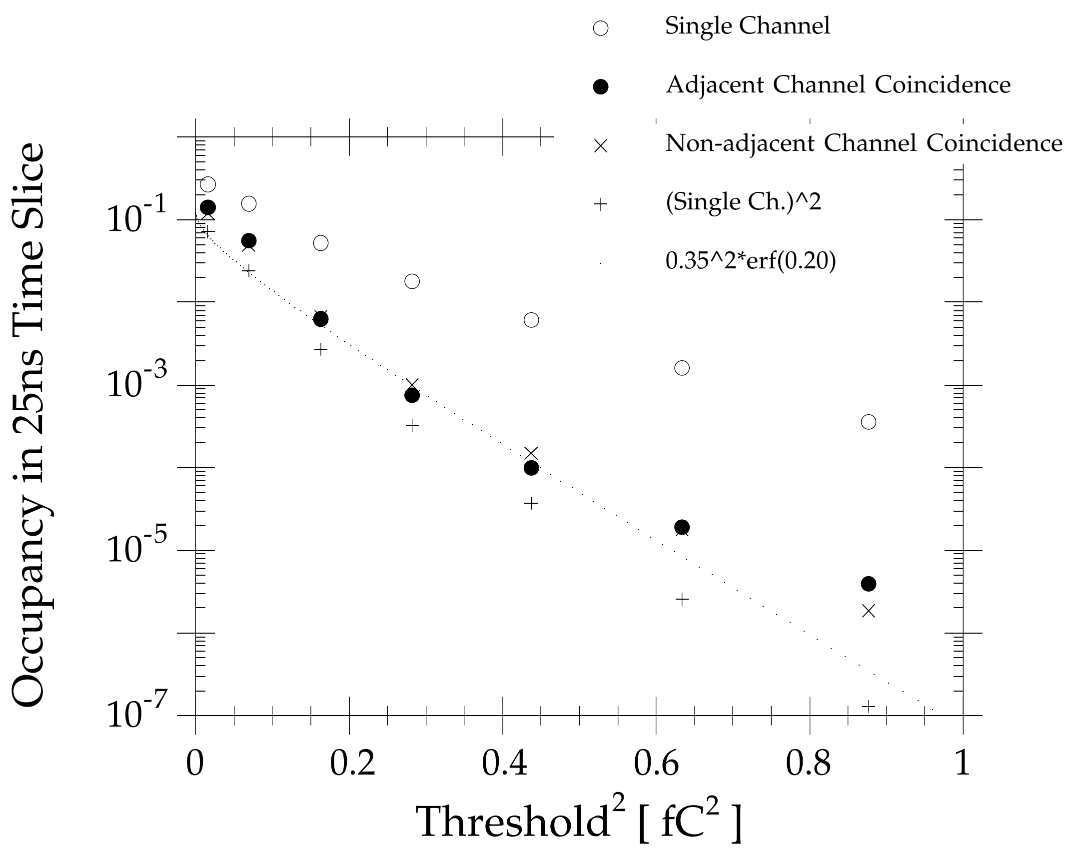

Fig. 1 Noise occupancy of single channels and of coincidences of two adjacent and two non-adjacent channels. The approximating error function and the expectation from Eq. 2 are also shown.

SINGLE CHANNEL NOISE OCCUPANCY

Fig. 2 shows the noise occupancy for an n-side detector which has been designed for low interstrip capacitance [10]. The data is presented as a function of the square of the threshold to show the approximate Gaussian behavior of the noise. A fit with a complementary error function Eq. 1 yields $O_O = 0.35$ and $\sigma = 0.275$fC and is also shown in Fig. 2. In addition, the measured coincidence occupancy of adjacent channels from Fig. 1 is plotted.

Using the fits to Fig. 1 and 2, we determine the single channel occupancy at 1fC to be $9.2*10^{-5}$, and the coincidence occupancy of adjacent channels at 0.5fC to be $1.5*10^{-3}$, i.e. the coincidence rate is 16 times larger than the single channel rate at twice the threshold.

If we try to preserve the low occupancy performance of the binary system in the two-threshold scenario, we can ask at what coincidence threshold the occupancy for the coincidence becomes equal to the single channel occupancy at 1fC. From Fig. 2, we find that this threshold equals 0.67fC.

Alternatively, if we are content with the worsened occupancy number of the adjacent channel coincidences, i.e. $1.5*10^{-3}$, we could lower the single channel threshold to 0.785fC and ease the monitoring requirements of the system. Note that the binary read-out system of the LPS in ZEUS [11] is operating with a threshold of 0.78fC, without common noise or occupancy problems. In addition, the resolution would be improved due to the increase in shared pulses recorded

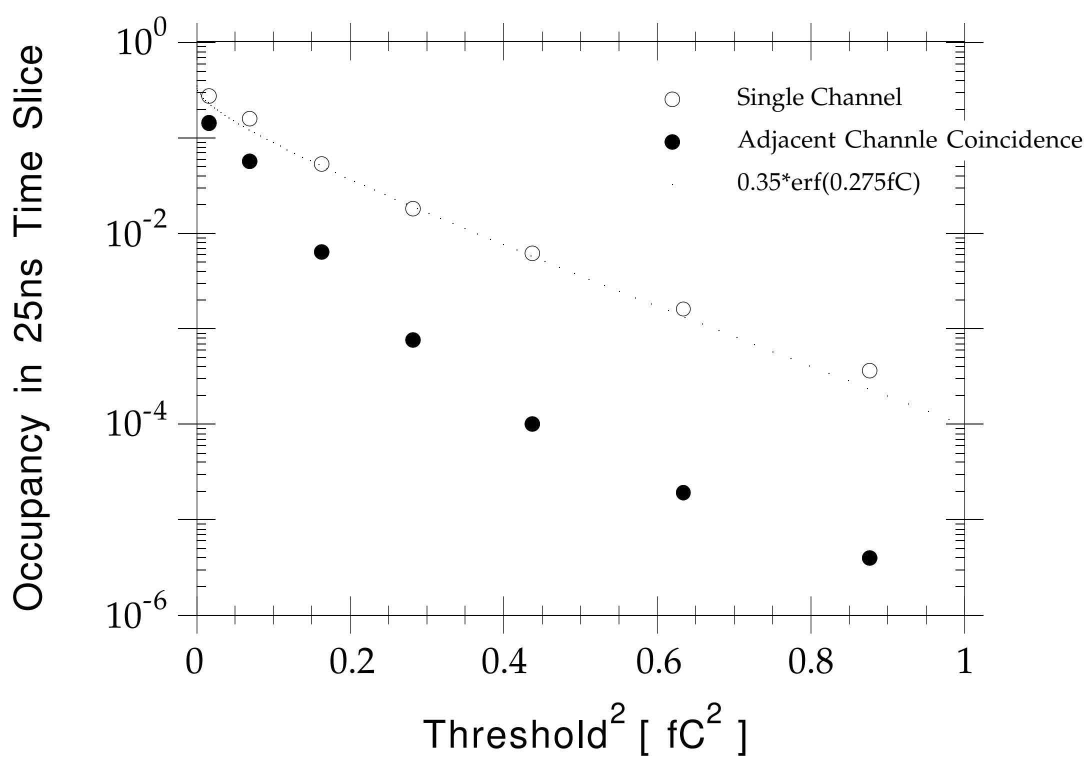

Fig. 1 Measure noise occupancy as a function of the square of the threshold for a 12cm long n-side silicon strip detector: single channel occupancy with error function fit Eq. 1 and coincidence occupancy of adjacent channels.

Table 1 summarizes the occupancies for the thresholds of 1, 0.785, 0.67 and 0.5fC, respectively. The threshold required for the coincidence to achieve the same occupancy as the single channel at 1fC is 0.67fC, instead of the planned 0.5fC. This corresponds to an operation of the single channel threshold at 1.34fC instead of 1.0fC , which is too high because it gives away some of the "efficiency head room" the binary system has at 1fC. For proper "crisp" functioning, the comparator needs an "over-drive" of about 0.25fC to minimize the time walk, and thus the minimum signal for an 1fC threshold is 1.25fC.

Table 1. Single Channel and Coincidence Noise Occupancy

Threshold [fC]	Threshold^2 [fC^2]	Single Ch. Occ	Adjacent Ch. Occ
1.0	1.0	$9.2 * 10^{-5}$	$< 10^{-6}$
0.5	0.25	$2.4 * 10^{-2}$	$1.5 * 10^{-3}$
0.67	0.45	$5.5 * 10^{-3}$	$9.2 * 10^{-5}$
0.785	0.615	$1.5 * 10^{-3}$	$2 * 10^{-5}$

CONCLUSIONS

Motivated by many suggestion in the ATLAS SCT collaboration on how to improve the binary read-out system for silicon strip detectors beyond the simple system developed for the LPS in ZEUS [11], we have investigated the consequences of adding to the single channel nominal threshold (about 1fC) a coincidence of two neighboring channels with half this threshold. We find that the noise occupancy of coincidences of adjacent channels with 0.5fC threshold each is about 16 times higher than the single channel occupancy at a threshold of 1fC. In order to achieve the same noise occupancy as the single channel, the coincidence threshold has to be raised to 0.67fC, which is judged too high. In the case that we are content with this higher occupancy, we could operate the single channel threshold at 0.785fC, extending the efficiency plateau and improving the resolution..

For completeness, we report two arguments against introducing lower thresholds, which are related to chip design :

a) in the binary amplifier-comparator chip, the comparator takes up about half the area of the chip: doubling the number of comparators will increase the chip size by 50%;

b) channel-to-channel matching, which is a key to low occupancy operation of the system, is harder to achieve at lower thresholds than at a higher one.

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