

Comparison between ATLAS forward microstrip detectors made on $6'' \langle 100 \rangle$ and $4'' \langle 111 \rangle$ crystal oriented silicon wafers^(*)^(**)

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Summary. — The noise seen by the front-end readout electronics of silicon microstrip detectors depends on the capacitive load on each channel and the shot noise due to the reverse current in the detector. Because of the short integration time of the LHC electronics (25 ns), the shot noise contribution is negligible as long as the current is kept to an acceptable level. However, any inter-strip capacitance increase after irradiation will degrade the noise performances of the detectors. A dependence of the capacitance on the crystal orientation of the silicon crystal used as a substrate for silicon detectors has been recently reported (Feld L. *et al.*, *Radiation induced changes in the Interstrip Capacitance of Silicon Microstrip Detectors*, 4th ROSE Workshop on Radiation Hardening of Silicon Detectors, CERN 2-4 December 1998, Published in CERN/LEB 98-11 (697)). We present here the results of irradiation of silicon microstrip detectors made on $6'' \langle 100 \rangle$ and $4'' \langle 111 \rangle$ crystal oriented silicon wafers in term of inter-strip capacitance and noise, measured using LHC speed binary electronics (LBIC, Spencer E. *et al.*, *IEEE Trans. Nucl. Sci.* **NS-42** (1995) 796), as a function of bias. A strong dependence of the inter-strip capacitance on the bias applied to the detector has been found for the irradiated detectors made on $\langle 111 \rangle$ silicon, but this dependence decreases with the frequency of the measurement. At high frequencies, which are the only ones relevant for the noise behaviour of the detectors, we found no differences at high bias voltages between the values before and after irradiation for detectors made on silicon with different crystal orientations. The effect on the noise has been checked and at the nominal operation bias we found no measurable differences between detectors made on silicon with different crystal orientations.

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1. – Introduction

The silicon detectors for the ATLAS semiconductor tracker (SCT) are designed to efficiently operate after a fluence of $3 \cdot 10^{14}$ protons cm^{-2} . Adequate operation is insured by requiring a signal-to-noise ratio (S/N) sufficient to allow full hit efficiency and negligible noise occupancy with binary readout electronics. After irradiation, a high bias voltage (350 V) will insure almost full charge collection, keeping the signal level close to the pre-irradiation value. Increased noise level is then responsible for reduction in the S/N ratio of irradiated detectors. The main source of noise due to the detector in the electronics is the capacitive load on each readout channel, which is determined by the capacitance of each readout strip to the back-plane and to the other strips. The inter-strip capacitance is dominated by that to the first and second neighbours on each side. The capacitance to the back-plane for the various detector geometries used for the ATLAS SCT detectors is between 0.25 and 0.35 pF/cm. The inter-strip capacitance is about three times higher and therefore constitutes the main contribution to the capacitive load.

We present the evaluation of the detector parameters (reverse current, inter-strip capacitance and noise) before and after irradiation, studying the impact of the use of 6" $\langle 100 \rangle$ and 4" $\langle 111 \rangle$ crystal oriented silicon wafers. The different crystal orientation, together with the oxide quality, can influence the density of trapped charges at the interface Si-SiO₂ in the inter-strip region and therefore the behaviour of the inter-strip capacitance.

2. – Pre-irradiation measurements

Wedge-shaped microstrip silicon detectors made by Hamamatsu Photonics [1] on 4" $\langle 111 \rangle$ crystal oriented and by Micron Semiconductor [2] on 6" $\langle 100 \rangle$ *n*-type silicon wafers were used for this study. They all have 768 strips with variable strip pitch due to the wedge shape. The average strip pitch was $\sim 60 \mu\text{m}$ for the Hamamatsu detectors and $\sim 75 \mu\text{m}$ for Micron ones. Both manufacturers used high-grade and high-resistivity FZ silicon, so the pre-irradiation full depletion voltage was between 50 and 65 volts for all devices. The detectors were able to sustain 1000 V bias, with a total reverse current of a few μA or less.

The detectors were glued to ceramics support frames and bonded to rebondable modules to be connected to 512 channels of binary readout electronics [3]. A pitch adaptor allowed the connection of the 768 strips to the 512 channels, pairing half of the strips together. The modules comprised a hybrid populated with four LBIC-CDP [4] chip sets. Figure 1 shows the schematic drawing of the binary electronics. The signal is amplified and shaped and the output level is compared with a reference threshold level (V_T) through a discriminator, giving a binary 1 if the signal is above the threshold. The threshold can be varied from 0 up to a few volts. A threshold scan can be used to determine the performance of the system in terms of its response to a given input signal and its noise. Different charges can be injected at the input of the preamplifier via a calibration capacitor to determine the (signal-dependent) gain.

The typical “*S curve*” obtained for each channel is shown in fig. 2. A fit with the complementary error function to this provides the response of the amplifier at zero signal (threshold voltage corresponding to 0.5 efficiency) and the noise of the system (FWHM of the derivative of the efficiency curve). Figure 3 shows the technique used to extract the noise value at each detector bias voltage. A threshold scan is run for different values of the injected charge to obtain the response curve and hence the gain of the amplifier as

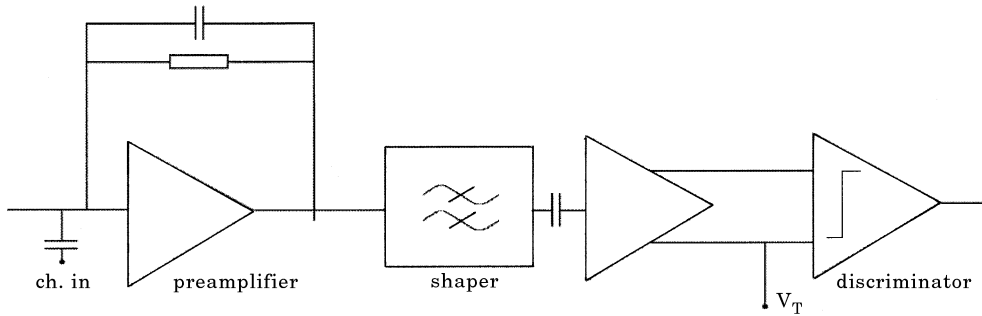


Fig. 1. – Diagram of the LHC speed binary electronics.

a function of the input charge is determined. The amplifier is designed with a reduced gain for high-injected charge to save power consumption. The input noise is evaluated by the measured output noise divided by the gain.

The final noise figure for microstrip detectors coupled to the electronics is dominated by the total strip capacitance. The noise increases linearly with the capacitive load, as shown in fig. 4 with the noise measured using LBIC electronics with various detectors for different strip length. The slope is about 65 enc/pF (the detectors were biased above full depletion for this measurement).

The behaviours of the inter-strip capacitance of non-irradiated $\langle 111 \rangle$ and $\langle 100 \rangle$ substrate detectors as a function of the applied bias voltage are shown in fig. 5. The inter-strip capacitance is roughly flat for the $\langle 100 \rangle$ substrate as a function of voltage, whilst it slightly decreases for the $\langle 111 \rangle$ substrate. In both cases the inter-strip capacitance is independent of the frequency of the measurement.

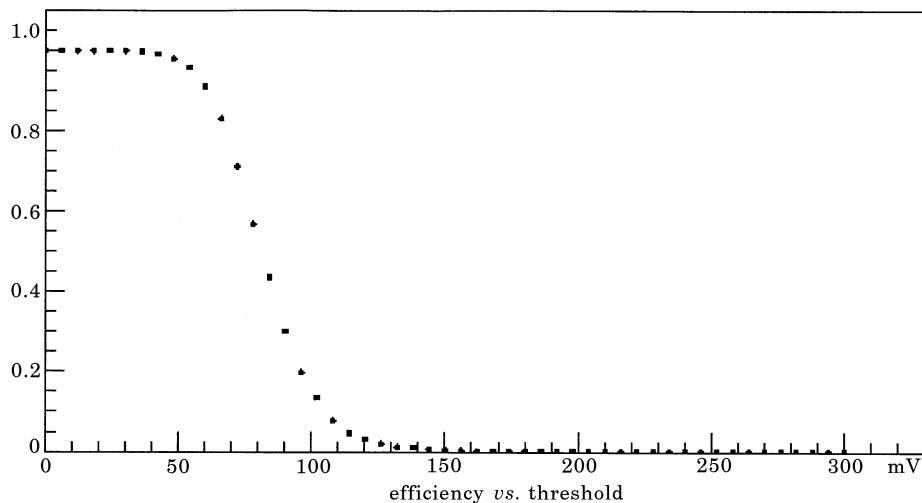


Fig. 2. – Example of an efficiency *vs.* threshold S-curve for the LBIC binary readout electronics.

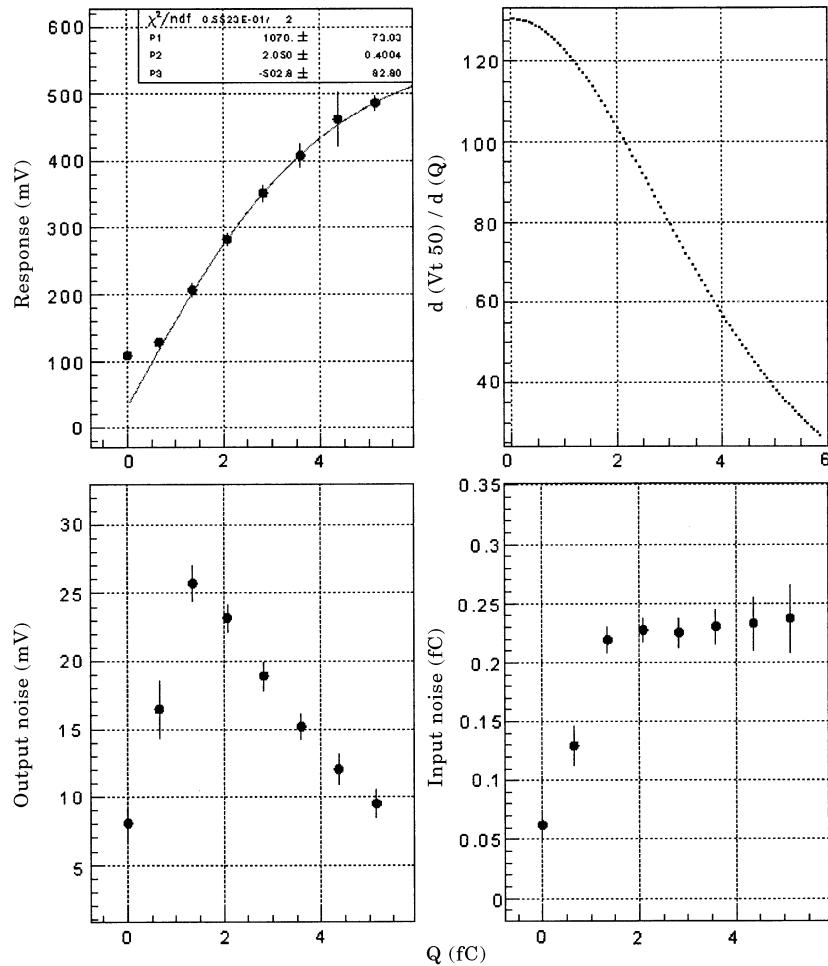


Fig. 3. – Response of the binary electronics to different input signals, evaluation of the gain and of the input noise.

3. – Results after irradiation

The detectors were irradiated with 24 GeV/c protons in dry atmosphere (N_2) under bias (100 V) and at -9°C in the CERN PS facility. The final dose was $3 \cdot 10^{14} \text{ cm}^{-2}$. After irradiation they were annealed for 7 days at 25°C , to simulate the anticipated annealing of the detectors at the LHC. Figure 6 shows the reverse current measured at $-17 \pm 1^\circ\text{C}$ for the two families of detectors up to 500 V. The measured value of the reverse current insures that the contribution of the shot noise to the total noise of the detector is negligible and indicates that no excess noise due to microdischarge should be anticipated [5].

Figure 7 shows the inter-strip capacitance measured for the two types of silicon with different crystal orientation. The inter-strip capacitance of the Micron $\langle 100 \rangle$ device remains flat as the applied bias increases. Slight frequency dependence is also observed. Both these features are much more pronounced for Hamamatsu $\langle 111 \rangle$ detectors.

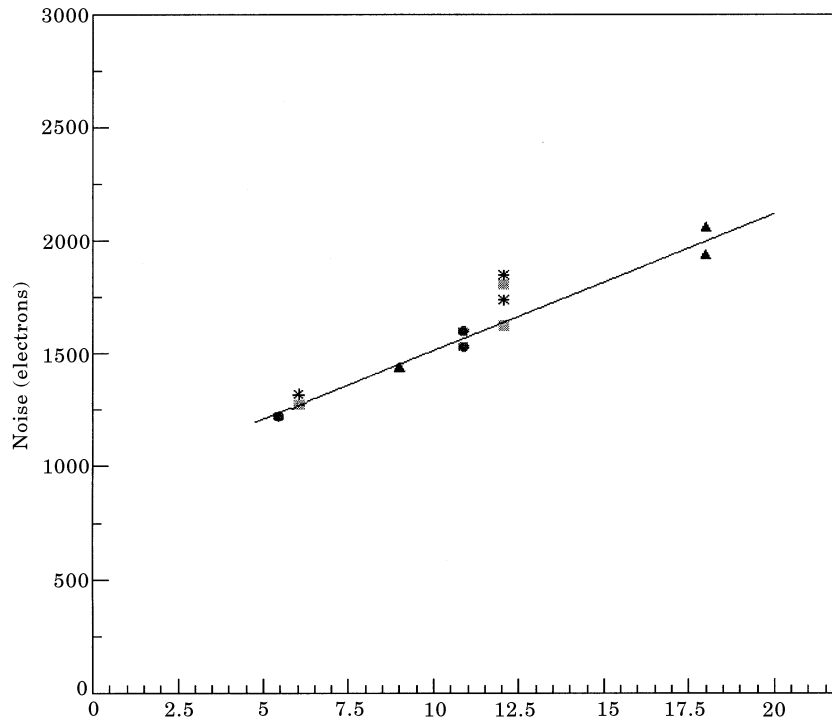


Fig. 4. - Noise measured with LBIC electronics *vs.* capacitive load. The noise was measured with various detectors with different strip length. The slope is about 65 enc/pF.

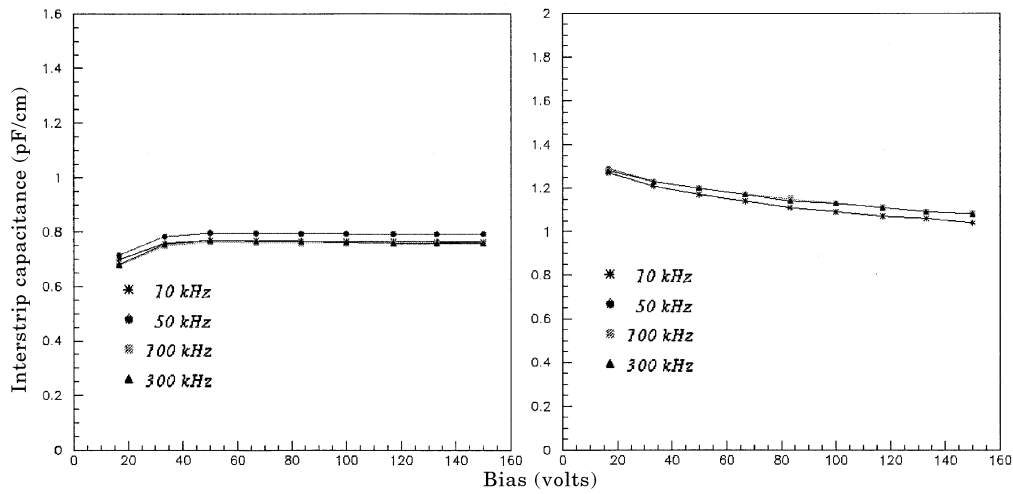


Fig. 5. - Inter-strip capacitance as a function of the bias applied to the detector for non-irradiated 4'' Hamamatsu <111> and 6'' Micron <100> crystal oriented silicon.

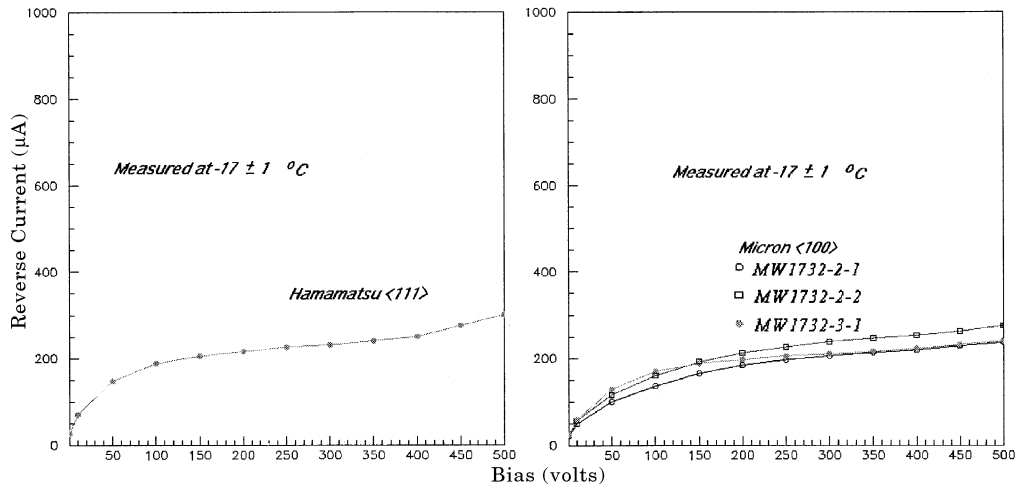


Fig. 6. - Reverse currents after $3 \cdot 10^{14} \text{ pcm}^{-2}$ for $\langle 111 \rangle$ and $\langle 100 \rangle$ crystal oriented silicon microstrip detectors.

Nevertheless, the inter-strip capacitance at 350 volts and 300 kHz after irradiation coincides with the pre-irradiation value.

After irradiation the noise, measured with binary electronics, is found to increase, compared to the pre-irradiation value, as shown in fig. 8. The noise does not, however, show any definite trend with increasing bias for Micron $\langle 111 \rangle$ or for Hamamatsu $\langle 100 \rangle$ detectors, as far as the precision of the measurement allows one to estimate.

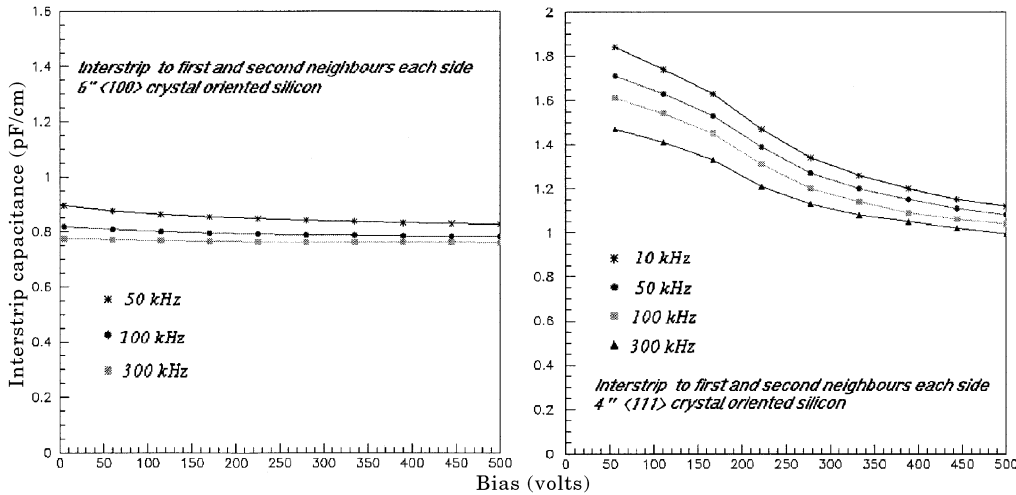


Fig. 7. - Inter-strip capacitance as a function of the bias applied to the detector for 4'' Hamamatsu $\langle 111 \rangle$ and 6'' Micron $\langle 100 \rangle$ crystal oriented silicon after $3 \cdot 10^{14} \text{ pcm}^{-2}$.

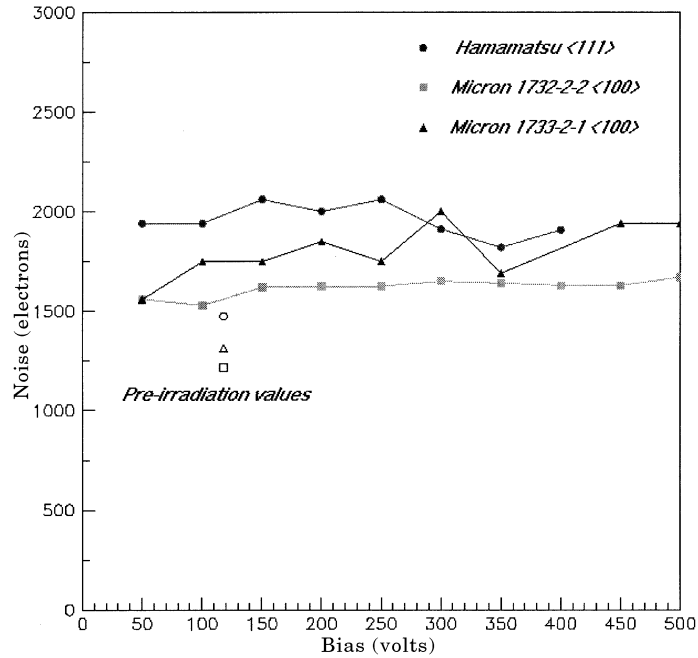


Fig. 8. – Noise *vs.* bias for Micron $\langle 100 \rangle$ and Hamamatsu $\langle 111 \rangle$ silicon microstrip detectors after $3 \cdot 10^{14} \text{ pcm}^{-2}$.

4. – Conclusion

After irradiation, Micron $\langle 100 \rangle$ 6'' detectors have flat inter-strip capacitance *vs.* bias behaviour. The Hamamatsu $\langle 111 \rangle$ 4'' detectors have inter-strip capacitance dropping with voltage but this effect is much less pronounced at higher (300 kHz) frequency, and the asymptotic post-irradiation inter-strip capacitance agrees with the pre-irradiation value. The noise seen with LHC speed binary electronics does not show any measurable trend in line with the behaviour of the inter-strip capacitance but instead looks independent of the voltage for both detector types.

For the post-irradiation high-voltage operation of silicon detectors, the noise performance shows no discernible correspondence with the different inter-strip capacitance behaviours of the $\langle 111 \rangle$ 4'' Hamamatsu and $\langle 100 \rangle$ 6'' Micron detectors.

REFERENCES

- [1] *Hamamatsu Photonics*, 1126-1 Ichino-cho, Hamamatsu 435, Japan.
- [2] MICRON Semiconductor, 1 Royal Buildings, Marlborough Road, Lancing, Sussex BN15 8UN (UK).
- [3] ROBINSON D. *et al.*, *Nucl. Instrum. Methods A*, **426** (1999) 28.
- [4] DE WITT J., *A pipeline and bus interface chip for silicon strip detector read-out*, *Proceedings IEEE Nuclear Science Symposium, San Francisco, CA, November 1993*.
- [5] OSHUGI T. *et al.*, *Nucl. Instrum. Methods A*, **342** (1994) 22.