Beamtest of Non-irradiated and Irradiated ATLAS SCT Microstrip Modules at KEK

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Abstract

Non-irradiated and irradiated ATLAS SCT barrel and forward modules equipped with ABCD chips were tested with the 4 GeV/c pion beams at KEK. Pulse shapes confirmed the peaking time of the amplifier to be less than 23 ns and broadening of the signals of the irradiated modules. Median charge saturated to 3.5 fC fast in the non-irradiated and slowly in the irradiated modules as a function of bias voltage. Signal/Noise ratios, using the noises from the in-situ calibration, were 16 in the non-irradiated, and 10 at 350V in the irradiated modules.

I. SUMMARY

Two types of silicon microstrip modules, barrel and forward, have been tested with the pion beams of 4 GeV/c at the 12 GeV proton synchrotron at KEK. The barrel modules were equipped with square silicon microstrip sensors of a physical size of 64 mm long and 63.6 mm wide with strips in parallel at a pitch of 80 µm. A module had a pair of sensors glued on the top and the other glued on the bottom side of a baseboard of the module, being angled at 40 mrad to have a stereo view. The strip length of a module was 12 cm by connecting the pair of sensors. The forward modules had a similar strip length but were wedge-shaped with a fan geometry of strips with an average strip pitch of about 80 µm. Strips were connected to the readout electronics, near the middle of the strips in the barrel module and at the end of the strips in the forward modules.

A module was equipped with 12 readout ASIC's (Application Specific Integrated Circuit), 6 on the top and 6 on the bottom side of the module on specially-designed hybrids. One ASIC read out 128 channels. The chips had been developed specifically for the readout of the silicon microstrip sensors of the SCT (Semiconductor Tracker) of the ATLAS detector for the LHC experiment, in order to readout the strips with on-off information. A single threshold circuitry was used in the ABCD2T version. Since the single threshold was found not sufficient for a required uniformity across the channels, an extra 2-bit modifier was introduced in the threshold circuitry in each channels, with other improvement in various circuitries, in the ABCD3T chips.

The SCT modules will accumulate a fluence of 3×10^{14} protons-equivalent/cm^2 over 10 years of operation, in the closest part to the interaction point. One of each barrel and forward modules were irradiated to the 24 GeV protons at the CERN proton synchrotron to the fluence. Two beamtests were carried out for the non-irradiated and irradiated modules with ABCD2T and ABCD3T chips. The modules of k3103, k3104, 011, 022, and 003 were prepared at KEK, FR-k81 at Freiburg, VAL-k3-166 and 165 at Valencia, and CG-k3-170 at CERN/Geneva. The classification of the modules is summarized in Table 1.

Table 1
Module name, type, ASIC, and irradiation characteristics in the beamtest

Beamtest		Name	Type	ASIC	Irradiation
1	mod0	k3103	barrel	ABCD2T	non-irrad
	mod1	FR-k81	forward	ABCD2T	non-irrad
	mod2	k3104	barrel	ABCD2T	non-irrad
2	mod1	011	barrel	ABCD3T	non-irrad
	mod2	022	barrel	ABCD3T	non-irrad
	mod3	003	barrel	ABCD3T	irrad
	mod4	VAL-k3-166	forward	ABCD3T	irrad
	mod5	VAL-k3-165	forward	ABCD3T	non-irrad
	mod6	CG-k3-170	forward	ABCD3T	non-irrad

The ABCD chips had a circuitry switching "edge detection mode" on and off. When the edge detection was off, the circuitry worked as a simple pulse-height discriminator sampling at the 40 MHz clock externally supplied. Since the beam arrival was random with respect to the clock, pulse-shape reconstruction was possible using the time between the beam and the clock, combining with threshold scans.

Taking the 50% efficiency points in fine time slices, the pulse shapes of the median charge were extracted for the non-irradiated (average of 011 and 022) and for the irradiated (003) modules as shown in Figure 1. Together shown in the figure is an impulse response curve of a third-order integration circuitry, CR-RC^3 which peaking time was fitted to be 23 ns to the non-irradiated module response.

From the comparison of the impulse and the non-irradiated module response, the peaking time of ABCD3T was faster than 23ns. Closeness of the impulse and the non-irradiated module response indicated that the main body of the signal current was at the beginning. Broadening of the pulse of the irradiated module was consistent with the flatter current caused by the type inversion of the silicon bulk, as shown in a simulation.

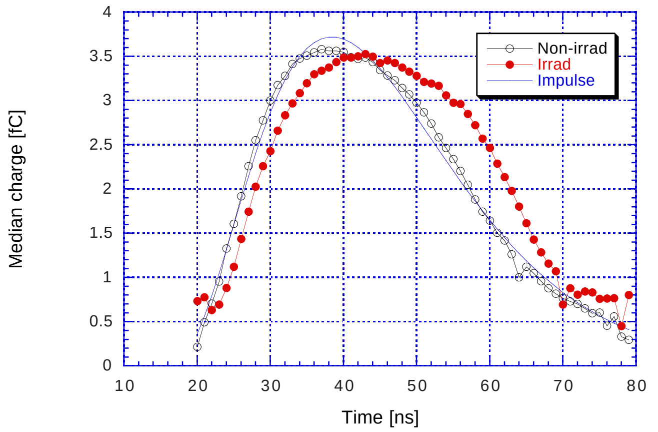

Figure 1: Pulse shape of the median charge of the non-irradiated (open circle) and irradiated (filled circle) modules, together with an impulse response of CR-RC^3 circuitry (solid line)

By selecting the time slices around the peak of the pulses, the median charges of each modules were obtained as a function of the bias voltage as shown in Figure 2. The median charges of the non-irradiated modules were saturating above 120V, at a charge of about 3.5fC. The saturation of the median charge of the irradiated modules was slower and was not saturating even around 500V. The full depletion voltage of the non-irradiated and irradiated sensors were expected to be around 70V and 300V, respectively.

The median charges of the forward modules were consistently higher than those of the barrel modules. This difference was understood due to the difference of the temperature of the chips in the modules which caused the scale change in the calibration DAC (digital-to-analog converter) output.

Using the calibration circuitry, the response and the noise of the ASICs were obtained in situ in the beamline. By using the noises, the “signal-to-noise ratio (Signal/Noise)” were obtained and shown in Figure 3. The fact that the Signal/Noise’s of the two modules of the barrel and of the forward coincided well indicated that the difference of the median charges within the barrel and the forward modules was due to the difference of the calibration capacitors of the ASIC’s. Lower Signal/Noise ratios of the forward module was also understood due to the higher temperature of the chips and the higher strip resistance seen from the amplifier input in the readout geometry.

Signal/Noise ratio of 16 in the non-irradiated barrel module was consistent with the specification of the ASIC’s. Signal/Noise ratio in the irradiated module was lower than the specification and reached 10 above 350V. Those of the forward modules were lower than the specification and an improvement in lowering the chip temperature is being considered.

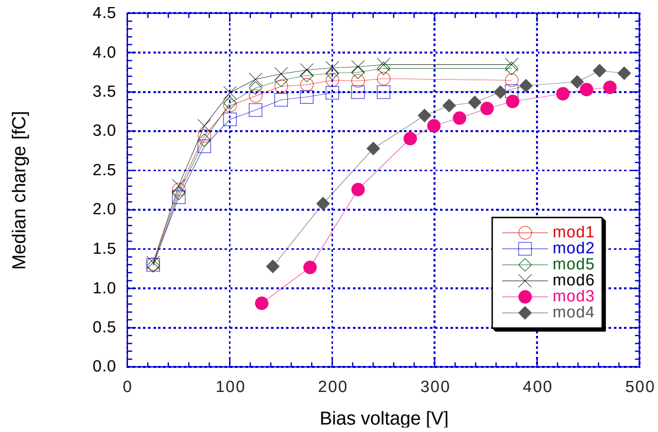

Figure 2: Bias voltage dependence of the median charges of the modules in the beamtest2. The voltages of the irradiated modules are corrected for the voltage drop in the series resistance in the bias feeding circuitry

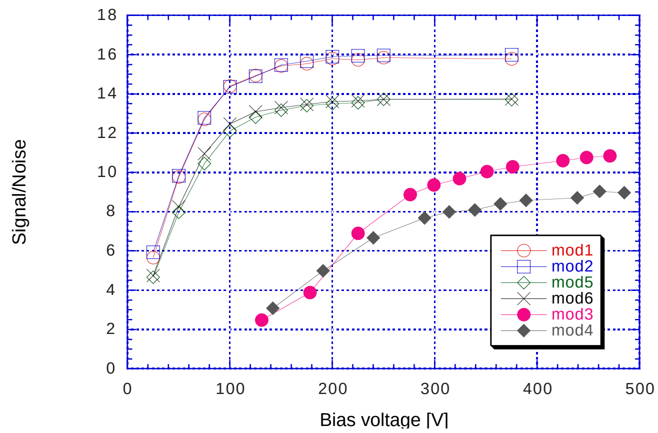

Figure 3: Signal-to-noise ratios as a function of bias voltage of the modules in the beamtest2