SCIPP 92/05
November 1992

Fermilab Library
0 1160 0019979 8

Radiation Hardness Measurements on Bipolar Test Structures and an Amplifier-Comparator Circuit

N. Cartiglia, D.E. Dorfan, D. Pitzl, J. Rahn
W.A. Rowe, H.F.-W. Sadrozinski, E.N. Spencer, M. Wilder
Santa Cruz Institute for Particle Physics
University of California, Santa Cruz, CA 95064
M. Turala
Institute of Nuclear Physics, ul. Kawiory 26A, 30-055 Krakow, Poland
W. Dabrowski
Institute of Physics and Nuclear Techniques, Krakow, Poland.

Abstract

We present radiation hardness measurements of both small-scale bipolar test structures and full amplifier-comparator circuits built in the same process. The motivation of this work is the design of a low-power, low-noise frontend with fast shaping for a silicon microstrip tracking detector for the SSC. We have irradiated BJT's (*npn* of various sizes and a lateral *pnp*), JFET's, diodes and resistors manufactured by Tektronix in their SHPi line to ^{60}Co doses of up to 5 Mrad and to fluences of up to $1.1 \cdot 10^{14}\text{cm}^{-2}$ of 650 MeV protons. Radiation effects on transistor noise and current gain, the value of the pinch-off voltage and output resistance of the JFET, leakage of diodes and resistor values are discussed. A full 64 channel amplifier-comparator circuit was exposed to 3.5 Mrad of gamma's and changes in gain and noise were measured.

I. Introduction

For the proposed silicon tracking device [1] of the SDC detector at the SSC [2] we are designing fast radiation-resistant front-end electronics chips. An additional requirement is the low power consumption of the front-end electronics ($\approx$ 1 mW/channel) to limit mechanical deformation within the required 5 μm stability and to reduce the mass of power bussing. These requirements can be met with a mixed technology frontend: a bipolar amplifier-comparator chip followed by a digital storage chip fabricated in radiation-hard CMOS [3].

In this paper we present measurements of parameters of the bipolar process SHPi produced by Tektronix [4] which are of consequence for the design of a bipolar amplifier-comparator chip at low standing currents (140 μA for the input transistor, $<$ 30 μA for all others). We investigated the current gain and I-V behavior as well as noise for transistors, leakage currents for diodes and resistance values before and after irradiation with total doses of up to 5 Mrad. How well these radiation effects are taken into account in the design is shown in the irradiation of a full custom designed amplifier-comparator chip of 64 channels [5], where both the noise and the gain were monitored.

II. Test Structures

The Tektronix SHPi bipolar process is a small geometry bipolar process that optimizes the *npn* transistors. The process replaces typical junction (p^+) isolation with recessed oxide isolation, which reduces the collector area. The minimum emitter shape (for the N1 transistor) is 1.3 μm $\cdot$ 3.6 μm, resulting in an f_t value of 9 GHz at 450 μA. The lateral *pnp* has a current gain β of about 40 and a f_t maximum of 100 MHz.

SHPi offers p-channel JFET's with $g_m/(2\pi C) = 600$ MHz, which is very fast. Vanadium Schottky diodes, both guarded and unguarded are available. There are three resistor types: NiChrome, implanted p^+ and implanted p^-.

III. Measurements and Irradiation

The aim of our test was to study the radiation effects on the DC parameters and characteristics as well as on noise of various components of the full custom bipolar process SHPi. We measured the basic DC characteristics of BJT's (various sizes of vertical *npn* and a lateral *pnp* transistor), JFET's, Schottky diodes, implanted resistors and NiChrome resistors. All DC measurements were done using a HP 4145B parameter analyzer. Noise measurements were limited to *npn* BJT's of various sizes considered as candidates for the preamplifier input transistor. For the measurements of the equivalent input voltage noise spectrum we have used the method developed previously for the noise measurements in rad-hard CMOS transistors [6]. The measurements of the noise spectra for different values of the collector current allow us to distinguish between two components of the equivalent input voltage noise, *i.e.*, the shot noise of the collector current and the thermal noise of the base spread resistance.

Presented at the IEEE Nuclear Science Symposium, Orlando, FL, October 27–31, 1992

The devices were irradiated in the ^{60}Co source at UC Santa Cruz up to a total dose of 5 Mrad with the rate of 20 krad/hr [7]. The measurements were taken in few steps at integrated total doses of 0 (pre-rad), 0.5, 1, 2.3, and 5 Mrad. Independently, some devices were irradiated in the 650 MeV proton beam at the Los Alamos National Laboratory [8] up to a fluence of $1.1 \cdot 10^{14}\text{cm}^{-2}$. Some parameters, like the current gain β of bipolar transistors were monitored during the proton run. All devices were biased during the irradiation in both tests.

Two 64 channel amplifier-comparator chips described in Ref. [5] were irradiated in the ^{60}Co source at UC Santa Cruz with full bias; 8 channels were monitored on each chip by determining noise and gain from the counting rate vs. threshold voltage curves taken at two known input charges. The measurements were taken pre-rad and after total doses of approximately 0.06, 0.12, 0.3, 0.8, 1.6 and 3.5 Mrad. It should be noted that only *npn* transistors and passive components are used in the chip design to enhance radiation hardness.

IV. Results

Of the variety of results obtained we discuss below only the parameters which exhibited significant changes after irradiation and/or are important for a design of low-noise, low-power, fast front-end circuits for silicon strip detectors.

A. npn Transistors

The most troublesome radiation effect in the bipolar transistors is the decrease of the current gain β, especially for low-emitter current densities. Fig. 1 shows, for the transistor N2, a typical behavior of the current gain β as a function of collector current I_c before irradiation and after a total dose of 0.5, 1, 2.3, and 5 Mrad as well as after a fluence of $1.1 \cdot 10^{14}\text{cm}^{-2}$ of 650 MeV protons.

Fig. 2 shows the current gain β as a function of dose for three different transistors N2, N8 and N32 at the same emitter current density 2.7 $\mu\text{A}/\mu\text{m}^2$. This current density corresponds to a collector current of 100 μA for the transistor N8, which in our design is a reasonable choice for the preamplifier input transistor. The data in Fig. 2 exhibit approximate scaling behavior before and after irradiation. Results obtained after the proton irradiation with a fluence of $1.1 \cdot 10^{14}\text{cm}^{-2}$, corresponding to a dose of 3.5 Mrad, are shown in the same plot. After proton irradiation, the current gain is significantly lower than after gamma irradiation with the same total dose and we conclude that although the majority of the radiation damage of protons is caused by ionization, we see significant displacement effects [9].

Other remarkable results for *npn* transistors after the dose of 5 Mrad are the following:

- The output resistance (forward Early voltage) does not change.
- The collector-emitter saturation voltage increases by about 100 mV.
- The collector leakage current increases from less than 3pA to up to 2–3 nA.
- Both the shot noise of the collector current and the thermal noise of the base spread resistance are unaffected by irradiation in distinction to the increase in noise of CMOS transistors [6].

B. Lateral pnp Transistors

The lateral *pnp* transistors available in the Tektronix process have relatively low current gain β (about 40) and relatively large emitter area (64 μm^2 for the minimum size transistor), so they can be expected to be sensitive to radiation damage.

Fig. 3 shows the current gain β as a function of the collector current for a minimum size *pnp* transistor before and after the total dose of 0.5, 1, 2.3 and 5 Mrad. The post-rad curve for protons is also shown. Recalling that the proton fluence corresponds to a total dose of 3.5 Mrad, we conclude that we observe significant displacement damage in the lateral *pnp* transistors, even more than in the *npn*'s.

We also observed a significant change in the I_c vs V_ce curve after a total dose of 5 Mrad. $I_c(V_{ce})$ shows a multistep knee for V_{ce} below 2 V. We see no change in the output resistance, for V_{ce} above 2 V, excepting a negative leakage current on the level of 2–3 nA on the collector.

C. P-channel JFET's

JFET's generally are the most radiation-resistant devices when compared with BJTs and CMOS transistors. They are majority carrier devices, so they are insensitive to the reduction of the minority carrier lifetime, and there is no oxide in these structures, so they don't show the sensitivity on ionization effects like CMOS devices.

After gamma irradiation we do not observe any changes in the output characteristics $I_d(V_{ds})$, in particular the pinch-off voltage and the output resistance remain unchanged. The gate leakage current increases, however, from the level of a few pA up to 1-2 nA. After proton irradiation we observe the increase of the pinch-off voltage V_p by 200 mV, probably a consequence of the decrease of the effective doping concentration in the channel due to displacement damage. If we compensate the shift of V_p by the external gate bias we obtain the same output characteristics as before irradiation with unchanged output resistance. After the proton irradiation, the same level of gate leakage current was observed as after the gamma test.

D. Diodes, Resistors

Schottky diodes, implanted resistors and NiChrome resistors showed remarkable radiation resistance to both photon and proton irradiation.

E. 64 Channel Amplifier-Comparator Chip

For the amplifier-comparator chip described in Ref. [5], Fig. 4 shows both the noise and the gain as function of total gamma dose. After 3.5 Mrad, we observe less than a 5% reduction in gain and less than 10% increase in noise. These measurements should be compared with the data of Fig. 2 where the current gain of the *npn* transistors is reduced to 60% after a gamma dose of 3.5 Mrad. One can conclude that careful designs can overcome the change in current gain during irradiation.

IV. Conclusion

The Tektronix SHPi process appears to offer sufficient radiation hardness for the design of fast, low-power amplifier circuits for the SSC.

Acknowledgments

We thank Emanuela Barberis, Will Clark and Daniel Goldin for their valuable contribution to the measurements. This work is supported in part by the U.S. Department of Energy, the Texas National Research Laboratory Commission and the National Science Foundation.

V. References

[1] A.J. Weinstein *et al.*, Subsystem R&D Proposal to Develop a Silicon Tracking System, SCIPP 89/39 (1989);
A.J. Weinstein *et al.*, SSC Subsystem R&D Proposal to Develop a Silicon Tracking System 1991, SCIPP 90/30 (October 1990);
A.J. Weinstein *et al.*, SSC Subsystem R&D Progress Report for a Silicon Tracking System, SCIPP 91/28 (September 1991).

[2] G.H. Trilling *et al.*, Letter of Intent by the Solenoidal Detector Collaboration to Construct and Operate a Detector at the Superconducting Super Collider, SSC-LOI0001, November 1990.

[3] H. Spieler, Power Requirements for Frontend Electronics in the Silicon Tracker, in SCIPP 91/28 (September, 1991). (See Ref. [1].

[4] Tektronix Inc., Beaverton, OR 97077.

[5] E. Barberis *et al.*, A Low Power Bipolar Amplifier Integrated Circuit for the ZEUS Silicon Strip System, to be published in *Proceedings of the 3rd International Conference on Advanced Technology and Particle Physics,* Como, Italy, June 22-26, 1992, SCIPP Preprint 92/35;
E. Barberis *et al.*, A Fast Shaping Amplifier-Comparator Integrated Circuit for Silicon Strip Detectors, contributed to the IEEE Nuclear Science Symposium, Orlando, Fl, October 27-30, 1992, SCIPP Preprint 92/40.

[6] W. Dabrowski *et al.*, Noise Measurements of Radiation Hardened CMOS Transistors, paper given at the 1991 IEEE Nuclear Science Symposium, Santa Fe, NM, October 4-7 1991, SCIPP 91/24.

[7] H. Ziock *et al.*, *IEEE Trans. Nucl. Sci.* **37**, 1238 (1990).

[8] H. Ziock *et al.*, *IEEE Trans. Nucl. Sci.* **38**, 269 (1991).

[9] Appreciable displacement damage were also observed by Rick VanBerg and Mitch Newcomer, University of Pennsylvania, private communication.

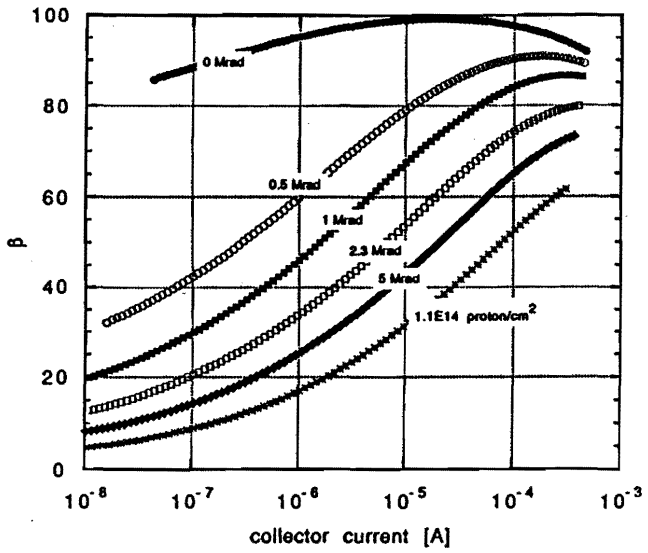

Fig. 1 The current gain β vs. collector current for the N2 *npn* transistor for different total ^{60}Co doses and a proton fluence of $1.1 \cdot 10^{14}$p/cm^2.

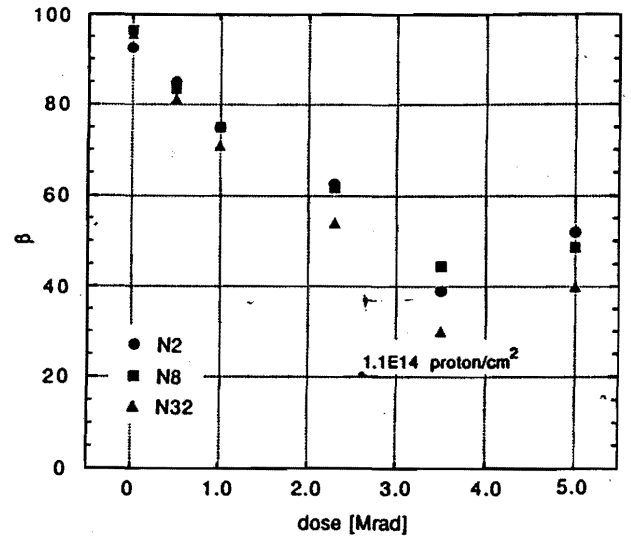

Fig. 2 The current gain β vs. total dose for three different *npn* transistors (N2, N8, N32) for the same emitter current density (corresponding to 100 μA for the N8 transistor). At a dose of 3.5 Mrad we have added the proton data.

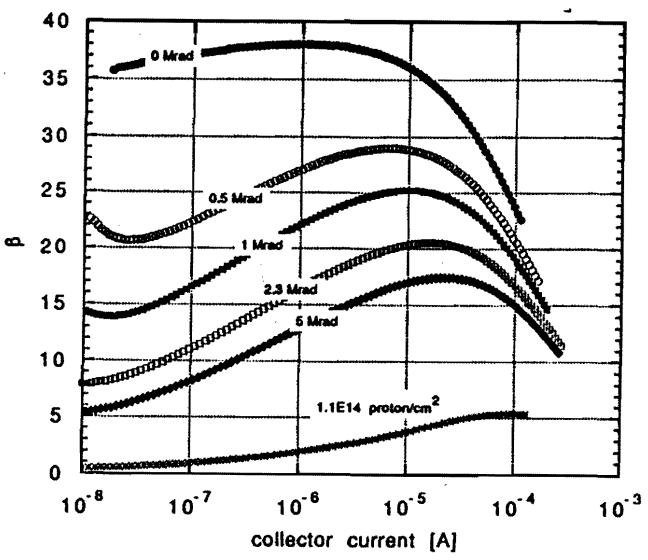

Fig. 3 The current gain β vs. collector current for the lateral *pnp* transistor for different total ^{60}Co doses and a proton fluence of $1.1 \cdot 10^{14}$p/cm^2.

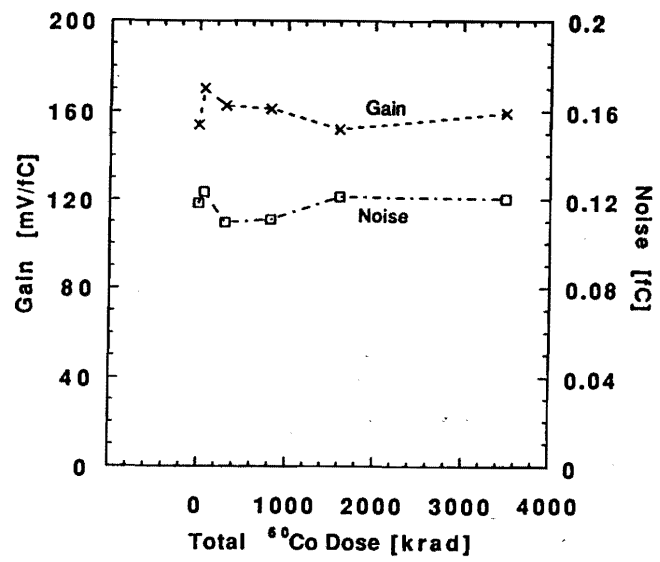

Fig. 4 The gain (left axis) and noise (right axis) of the amplifier-comparator chips of Ref. [5] during ^{60}Co irradiation.