EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PPE/93-141
21/07/1993

VIKING, A CMOS LOW NOISE MONOLITHIC 128 CHANNEL FRONTEND FOR Si-STRIP DETECTOR READOUT

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Abstract

A low noise Si-Strip detector readout chip has been designed and built in 1.5 μm CMOS technology. The chip is optimized w.r.t. noise. Measurements with this chip connected to several silicon strip detectors are presented. A noise performance of ENC = 135 e- + 12 e- / pF and signal to noise ratios between 40-80, depending on the detector, for minimum ionizing particles traversing 280/300 μm silicon has been achieved.

To be submitted to Nuclear Instruments and Methods

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1. Introduction

There is particular interest to develop very low noise frontends for silicon strip detector readout in view of the small signal charge obtained from minimum ionising particles in thin silicon detectors. Both precise measurement of charge sharing between strips due to charge diffusion, which is important to achieve the best spatial resolution, and accurate charge correlation on both sides of double side readout strip detectors for pattern recognition purposes require lowest possible noise in the readout. Other applications of strip detectors, where low noise plays an essential role is the detection of low energy β radiation and X-rays. A low noise silicon strip readout VLSI chip, called VIKING, has been designed and constructed in 1.5 micron CMOS technology. In this paper the basic design, layout and performance of this chip is described and results from measurements with several different strip detectors are presented.

2. The Circuit

Developed from a CMOS low noise amplifier-shaper 4 channel prototype [NIMA, 301, 1991, 506] the chip contains 128 low power [1.5 mW/channel] charge sensitive pre-amplifiers followed by CR-RC shapers and sample & hold circuitry, input & output multiplexing and one output buffer as shown in fig. 1. Use of time continuous shaping facilitates triggered applications and enables optimum signal to noise ratios to be chosen for various detectors typically for LEP or PETRA experiments. The peaking time has been choosen for these applications to be around 1.5 μs. Specific features of this design are the ability to trigger on asynchronous external signals in contrast with 'switched capacitor' devices and to clock the input & output to any channel to perform detailed studies of the amplifier like noise or signal shape.

The extensive and consistent use of current-mirroring and externally controled bias currents minimises the effect of threshold changes due to radiation damage. Because of the differential, low impedance terminated, output stage which has a fast settling time [less than 100ns], a maximum readout clock frequency of more than 10 Mhz can be obtained. An analog and a digital reset may be applied to the chip at any time, also during the readout cycle. To minimize noise injection, all digital clocks are balanced differential. For the timing of the digital signals see fig. 2. For details concerning the pre-amplifier and shaper design see fig. 3 & ref. 1. All necessary analog and digital inputs as well as the outputs are described in appendix 1.

3. Measurements

3.1 Noise Evaluation Of The VIKING Chip.

The VIKING offers the possibility to select a single channel and perform detailed measurements. Fig. 4 shows a single shot output of the VIKING chip for an injected charge corresponding to a signal of a minimum ionizing particle penetrating 280 μm of silicon. The noise of the bare chip has been measured by injecting a voltage step of 2 mV across a 1.8 pF capacitor directly into several inputs. A small amount of external noise pick up has been subtracted by common mode noise correction using simultaneous measurements on eight separate channels on the same chip. These measurements have been done for two different shaping times. A RMS noise of ENC = 125 e^- + 14 e^-/pF was measured for 1.5 μs peaking time and ENC = 136 e^- + 12 e^-/pF for 2 μs peaking time. Detailed results are shown in fig. 5.

Most of the measured noise is due to the white noise coming from the channel resistance.

3.2 Noise Contributions Of A Detector Chip System.

In addition to the noise of the input FET of the pre-amplifiers which is proportional to the load capacitance any detector will contribute additional noise. The two main noise sources in the AC coupled detector are the leakage current and the bias resistor. All noise sources referred to the input of the amplifier are [1]:

$$ENC_{preamp} = 136\ e^- + 12\ e^-\ C_{load}\,[\mathrm{pF}]$$

$$ENC_{leakagecurrent} = \frac{e}{q}\sqrt{\frac{q\ I_{dl}\ T_p}{4}} = 130\sqrt{I_{dl}\,[\mathrm{nA}]}$$

$$ENC_{biasresistor} = \frac{e}{q}\sqrt{\frac{T_p\,kT}{2R_p}} = \frac{946}{\sqrt{R_p[\mathrm{M\Omega}]}}$$

Here $\mathbf{C_{load}}$ is the external load capacitance, $\mathbf{e} = 2.718$,q the electron charge, $\mathbf{I_{dl}}$ the diode leakage current, $\mathbf{T_p}$ the peaking time (1.5 μs), **k** the Bolzman constant, T the absolute temperature in Kelvin and $\mathbf{R_p}$ the parallel resistance of the bias resistor and the feedback resistor of the pre-amplifier. The total noise can be calculated as :

$$ENC_{total} = \sqrt{ENC_{pa}^{\ 2} + ENC_{lc}^{\ 2} + ENC_{br}^{\ 2}}\ [\mathrm{rms}\ e^-]$$

3.3 Measurements With Detectors

Measurements were done with three different detectors having 280 or 300 μm thickness. First a double sided detector with 100 μm readout pitch and 20 mm long strips parallel on both sides [A], second a single sided detector with 50 μm readout pitch and 45 mm long strips [B] and third a single sided detector with 25 μm readout pitch and 12 mm long strips [C].

All detectors were exposed to β's from a ^{90}Sr source. A cross check with X-rays from a ^{241}Am of 59.8 keV shows that the most probable energy value in the Landau-like ionisation distribution measured for β's from the ^{90}Sr is comparable to the most probable energy from a minimum ionizing particle [MIP] traversing 280 μm of silicon. The parameters of the 3 detectors used for the tests are summarised in table 1 .

TABLE 1

detector	A	B	C
readout on	p^+ & n^+	p^+	p^+
size	8 x 20 mm^2	45 x 45 mm^2	12 x 12 mm^2
strip length	20 mm	45 mm	12 mm
thickness	280 μm	280 μm	300 μm
readout pitch	100 μm	50 μm	25 μm
R_{bias}	5-8 MΩ	30 MΩ	100 MΩ
I_{leak} /strip	5 nA	0.1 nA	0.02 nA
strip capacitance	1.6 pF	10 pF	10 pF
deplation voltage	50 V	50 V	40 V

Table 1.: The static properties of the detectors used in these tests.

The data acquisition system consisted of a VIKING driver unit in NIM standard and a VME ADC buffer unit [SIROCCO]. The VIKING driver generates all necessary clock signals for the VIKING readout chips. The SIROCCO digitizes the multiplexed analog output of the chips. Before acquiring data, the pedestal (average baseline) and noise (RMS of the pedestal) is determined for each channel. Common mode pick up is removed on a chip by chip bases. Dead and noisy channels are removed. The S/N ratio is calculated with the signal being the total cluster charge and the noise the single channel noise. For the detector A the most probable signal over noise ratio of 41 (corresponding to a noise of 550 rms e^-) on the p-side and 16.8 (corresponding to a noise of 1330 rms e^-) on the n-side was measured for ^{90}Sr. The high noise on the n-side is at present not understood. The charge correlation measured on n-side and p-side of this detector is shown in fig. 6. The same source has been used with detector B and the most probable S/N ratio of 68.7 (326 rms e^-) was measured. Detector C has been connected to readout chips on both sides of the p^+ diodes in a way that one could obtain with the 50 μm pitch of the VIKING a readout pitch of 25 μm. In this case we measured a most probable S/N ratio for the β's from the ^{90}Sr of 77 (312 rms e^-)(Fig.7). The

X-rays of 59.8 keV from ^{241}Am were measured with a peak S/N ratio of 59.4. The results from the measurements are summarised in table 2.

TABLE 2

detector	A	B	C
ENC [rms e-] for 1 MIP calculated	533	318	300
ENC [rms e-] for 1 MIP measured	547 (1330 on the n^+ side)	326	312

Table 2.: Summarised results of the three detectors used in these tests.

4. A Prestudy for Imaging Applications

In order to demonstrate good spatial resolution imaging capabilities with silicon strip detectors equipped with low noise VIKING type frontends a specially structured radioactive source was fabricated by the CERN radioprotection group. Drops of a ^{35}S (β emitter) solution (E_{av} = 48.8 keV & E_{max} = 150 keV) were deposited in precise holes of 1.5 mm diameter and at a distance of 3 mm (fig.8a) on a ceramic substrate. This source has been placed on detector C in direct contact, the holes facing downwards. Hits from β's coming from this source were recorded. The measurement intensity distribution can be seen in fig.8b. One can clearly see a good image of three of the holes filled with ^{35}S with relatively sharp edges. Some smearing is expected from paralax effects since no special effort has been made to put the ceramic substrate completely flat on the detector surface. These measurements have been done as a prestudy to evaluate imaging capabilities with a new version of the VIKING chip with self triggering capability which is under development.

5. Radiation damage

VIKING readout chips were exposed to electron irradiation (2 MeV) with a total dose of 50 krad and noise versus capacitive load was measured again. Results as shown in fig.9. The baseline noise and the noise slope have increased by 38 % which is acceptable for most applications. Furder irradiations of this chip are under way.

6. Summary

It has been demonstrated that the new low noise frontend chip VIKING bonded to high quality silicon strip detectors allows to achieve signal to noise ratios of up to 80 for minimum ionising particles traversing 300 μm of silicon. The potential of using this frontend circuit for imaging applications with silicon strip detectors has been shown. It has been demonstrated that the VIKING chip keeps agood performance at least up to 50 krad of total irradiation dose. Two of the detectors with the best signal to noise ratio of 80 have been put into a high energy particle beam to measure their spatial resolution. Results from this test will be presented in a forthcoming publication.

Appendix

1.0 Timing of VIKING

'Clockb' and 'shift-in' activate the start & stop unit in the chip, which creates an internal clock (clocki), a 'start' signal for the shift registers and an activate signal (ero) for the output buffer. 'Ero' is necessary to allow daisy chaining of chips and hence only one output buffer at any time should be switched on. The 'start' goes into the output multiplexer and 'clocki' shifts it through the 128 channels so that each channel is for one clock cycle connected to the output buffer to read the channels out. 'Test-on' enables the input multiplexer to operate in parallel with the output multiplexer. That gives the opportunity to calibrate the amplifiers with a charge given through the cal input. After 128 clock cycles the outcoming 'shift in' from channel 128 stops the internal clock, disables the output buffer and creates a shift out which can be used as a shift-in for the next readout chip.

2.0 I/O -Description of Viking

Digital I/O :

('1'= +2 V & '0' = -4 V)

Inputs

delay_on	'1' turns on the delay-unit for the hold signal (optional)
hold	Hold is performed on the falling edge. '1' is tracking and '0' is hold mode.
hold_b	(dummy)
areset	Reset of the anolog output. Performed on the falling edge. '1' is active and '0' is reset. (optional)
areset_b	(dummy)
dreset	Reset of all the digital elements. Performed on the rising edge. '1' is rest and '0' is active.
dreset_b	(dummy)
clock_b	Performed on the falling edge.
clock	(dummy)
test_on	'1' turns on the test-mode
shift-in_b	Performed on the falling edge

Outputs

shift-out	'0' when the 128 th clock_b is '0' ; '1' else

Analog I/O

Inputs

vref	Reference voltage for the differential output buffer. Optional, since it is generated internally.
delay_adjust	Current input adjusting the time delay T_d of the hold signal. ($I_d = 15/T_d$ [μA]) (Optional)
vfs	Biasing voltage determining the resistance of the feedback transistor of the shaper.(-1.0 V)
vfp	Biasing voltage determining the resistance of the feedback transistor of the preamplifier. (100 mV) Should be as low as posible (parallel resistance noise)
cal	Voltage step test-input across an external capacitor. Can be used only if test_on is '1'.
shabias	(sh_13) Biasing current for the shaper.(20-70 μA) Adjusts the shaping time A single resistor connected to VSS can be used
prebias	(pa_9) Biasing current for the preamplifier. (210 μA) A single resistor connected to VDD can be used.
bufbias	(Ibuf) Biasing current for the output buffer. (140 μA) A low impedance voltage source should be used .

OUTPUTS

outp,outm	anolog outputs. Terminate with 600 Ω. Termination to GRN and VSS.(i.e.to -2V)

GND	**0 V**
DVSS & AVSS	**-4 V**
DVDD & AVDD	**+2 V**

Fig. 1

Blockdiagram of the VIKING with input & output multiplexing.

Fig. 2

Timing diagram for the VIKING. To capture the output of the preamplifier-shaper a 'hold' signal has to be applied according to the chosen shaping time. The internal delay circuit allows to give 'hold' before the trigger occurs so that during the sensitive time no digital signals are applied to the chip. Once the charge is stored the chip can be read out with 'clock' & 'shift-in'.

Fig. 3

Schematic diagram of one channel of the VIKING including preamplifier, shaper and sample & hold.

Fig. 4

A single shot output of the VIKING for an injected 2 mV across a 1.8 pF capacitor. This charge is equivalent to that created by a minimum ionizing particle traversing 280 μm silicon. The peaking time is 2.0 μs.

Fig . 5

ENC of the VIKING vs load capacitance for different shaping times. The noise was measured simultaneously from several channels and common mode correction was applied.

Fig. 6

Charge correlation p-side vs n-side of detector A and VIKING with ^{90}Sr betas.

Fig. 7

Charge of ^{90}Sr betas collected with detector C and VIKING. The most probable signal over noise ratio is 77 (fit value).

Fig. 8 a&b

Imaging application studies with the VIKING and detector C. The regular pattern of the holes of the source can be seen clearly in the intensity distribution.

Fig. 9

ENC vs load capacitance of the VIKING after irradiation with 50 krad electrons of 2 MeV.

Fig. 10

Detailed structure of the VIKING

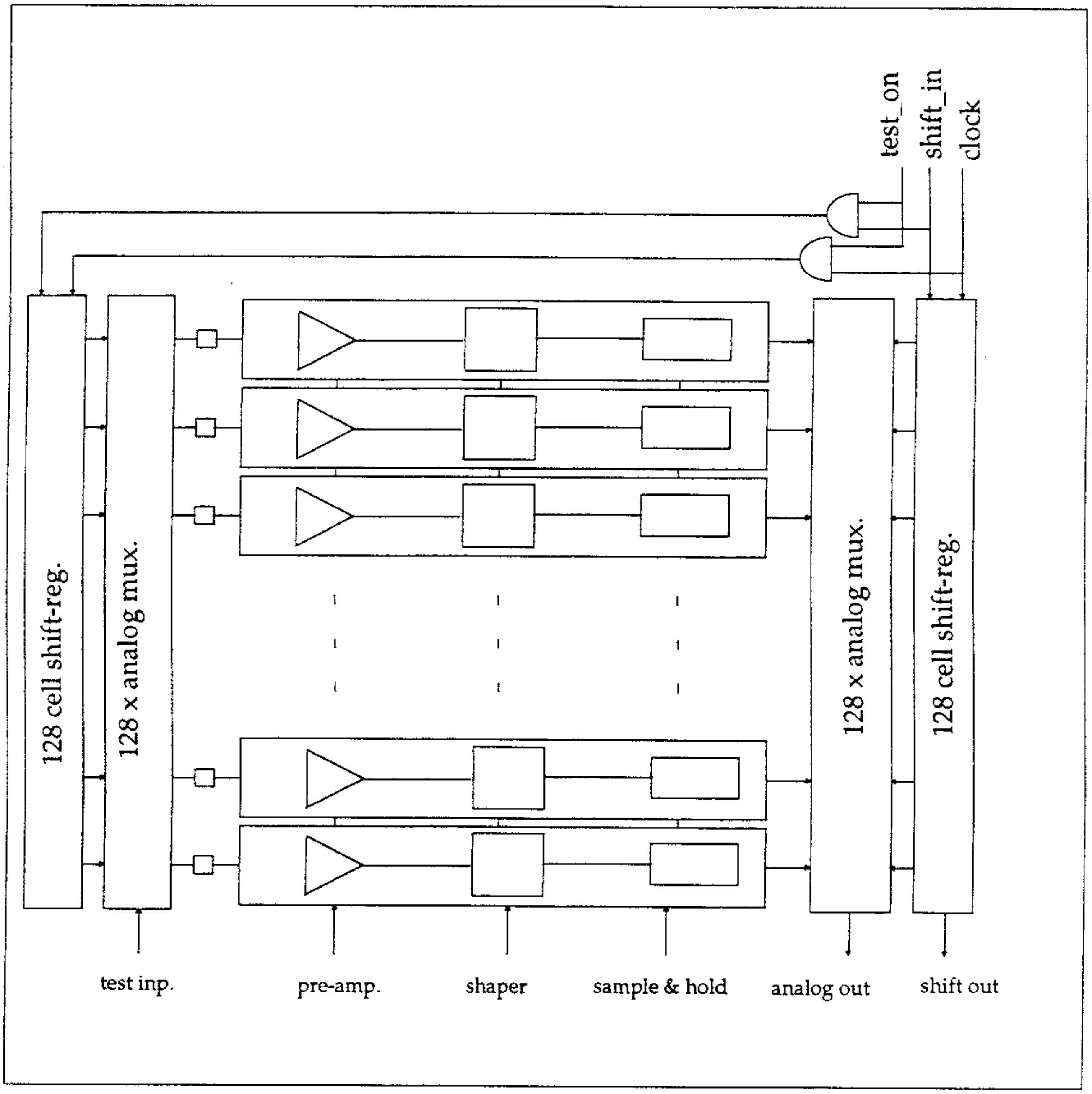

test_on
shift_in
clock
128 cell shift-reg.
128 x analog mux.
128 x analog mux.
128 cell shift-reg.
test inp.
pre-amp.
shaper
sample & hold
analog out
shift out

Fig. 1

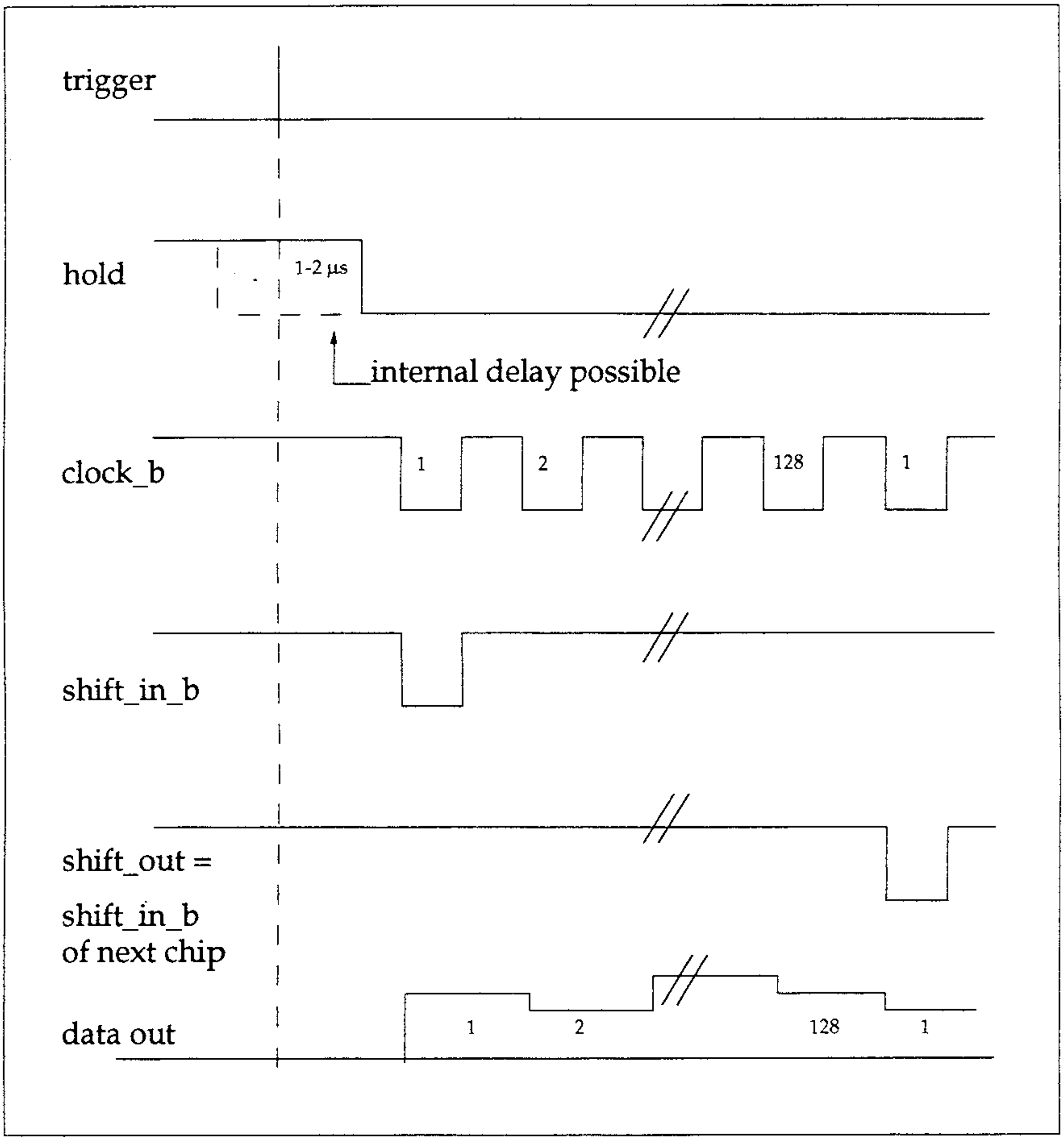
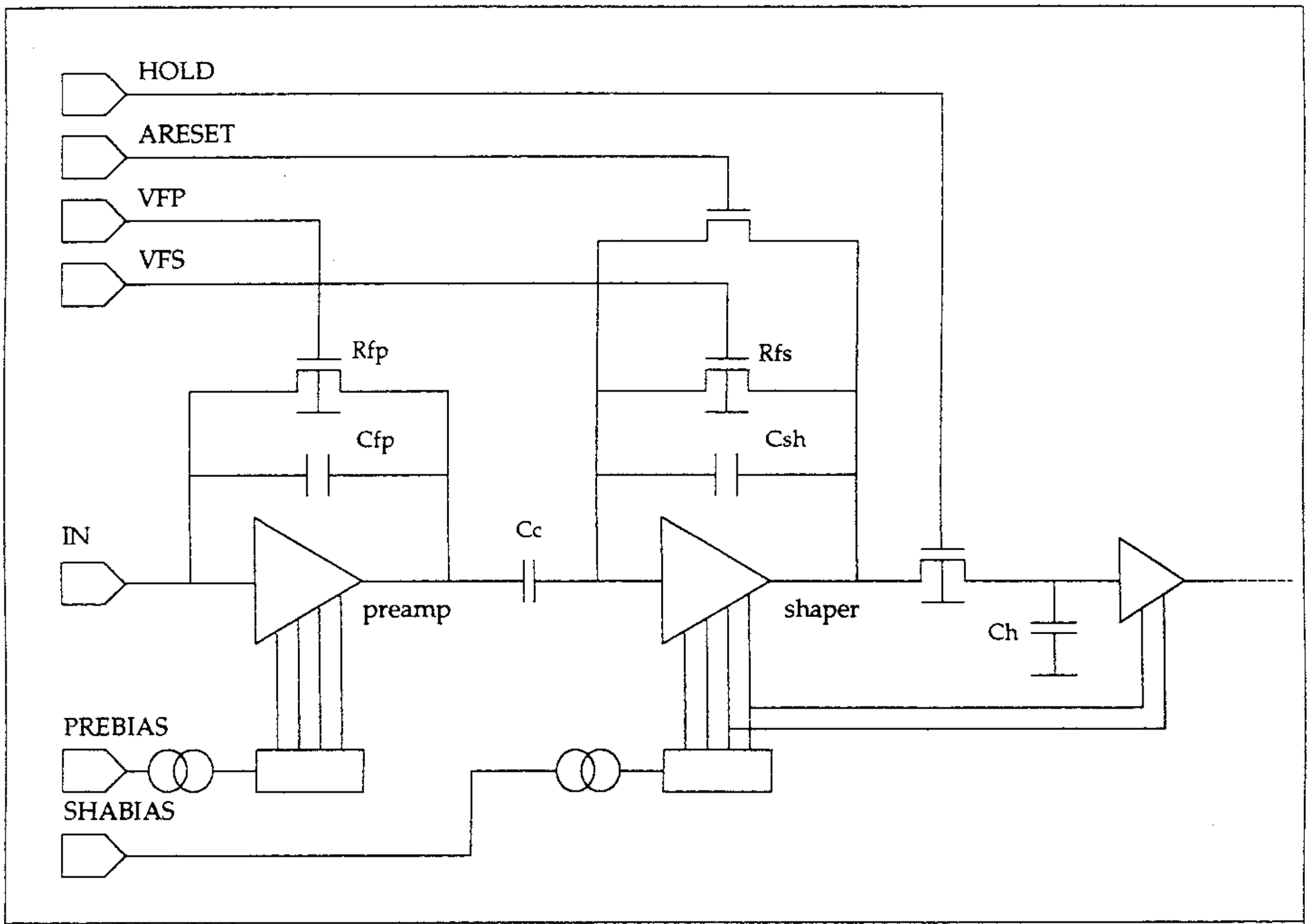
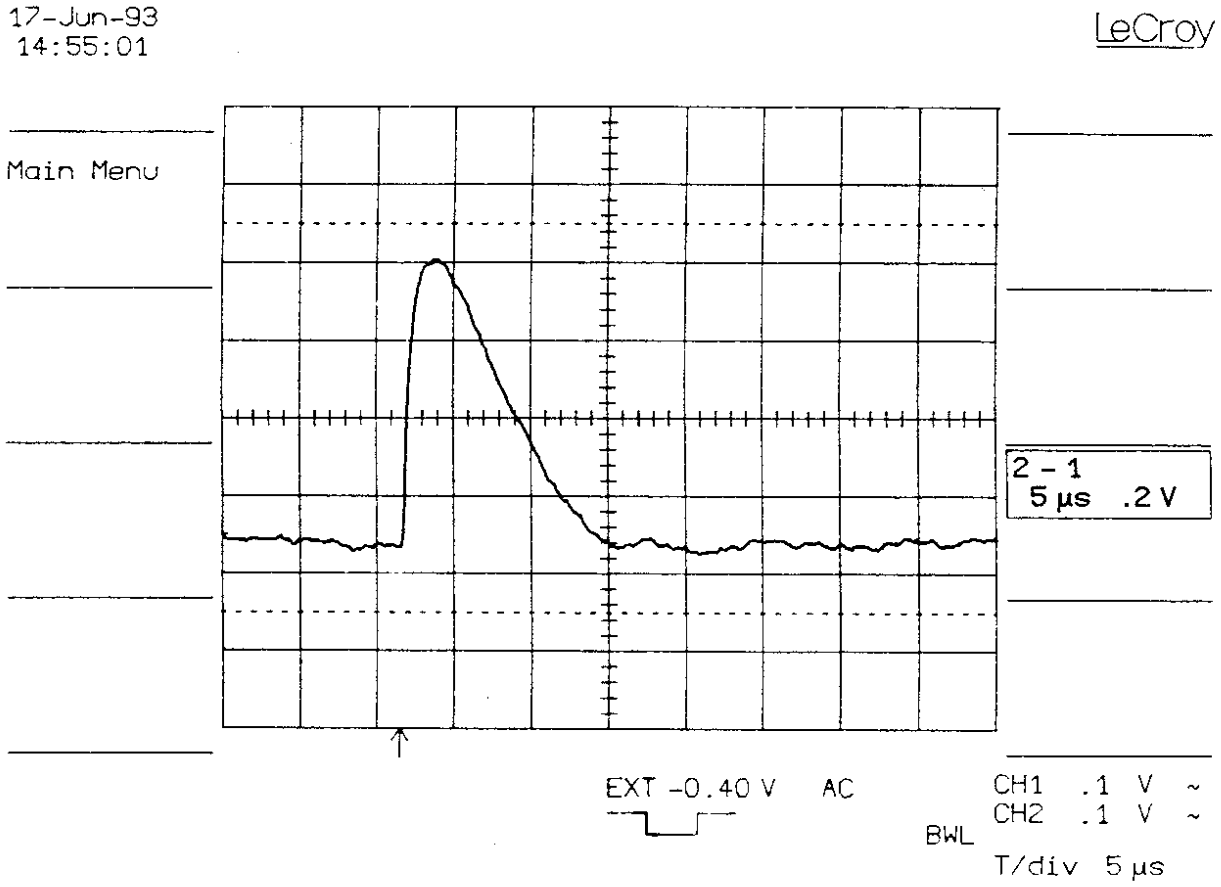

trigger
hold
1-2 µs
internal delay possible
clock_b
1
2
128
1
shift_in_b
shift_out =
shift_in_b
of next chip
data out
1
2
128
1

Fig. 2



Rfp > 50 MΩ	Rfs ≈ 6 MΩ	Cc ≈ 6 pF	Ch ≈ 10 pF
Cfp ≈ 0.6 pF	Csh ≈ 10 pF	Tpeak 1-2 µsec	
DC drain curr. 170 µA	DC drain curr 10 µA	Power consumption 1.2 mW/channel	

Fig. 3


17-Jun-93
14:55:01
LeCroy
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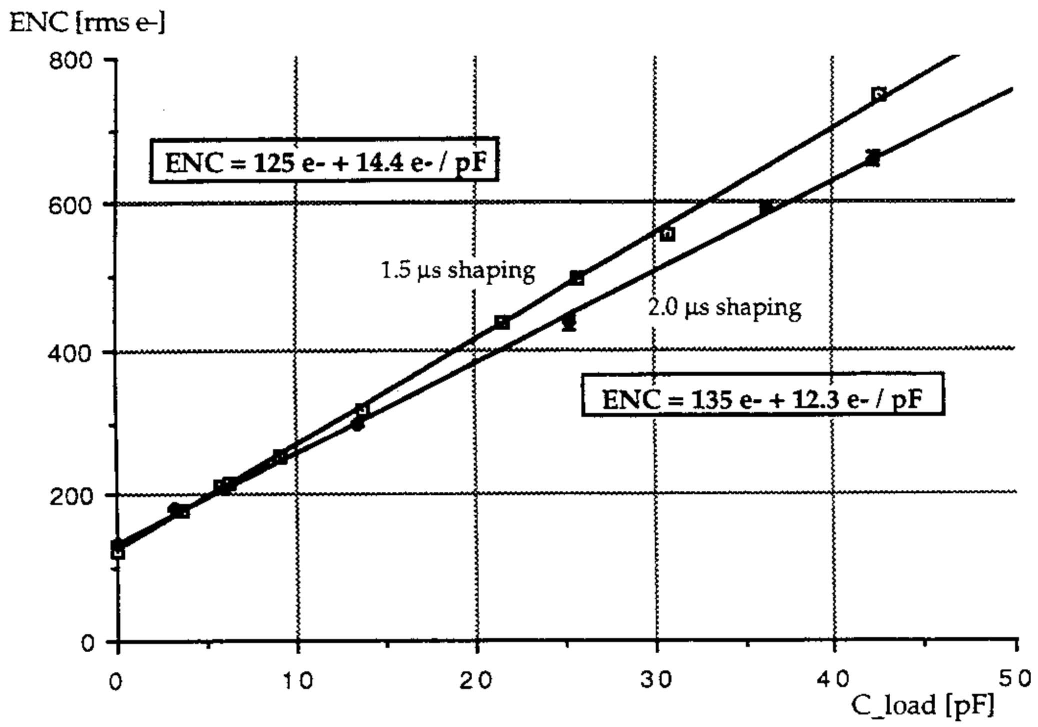
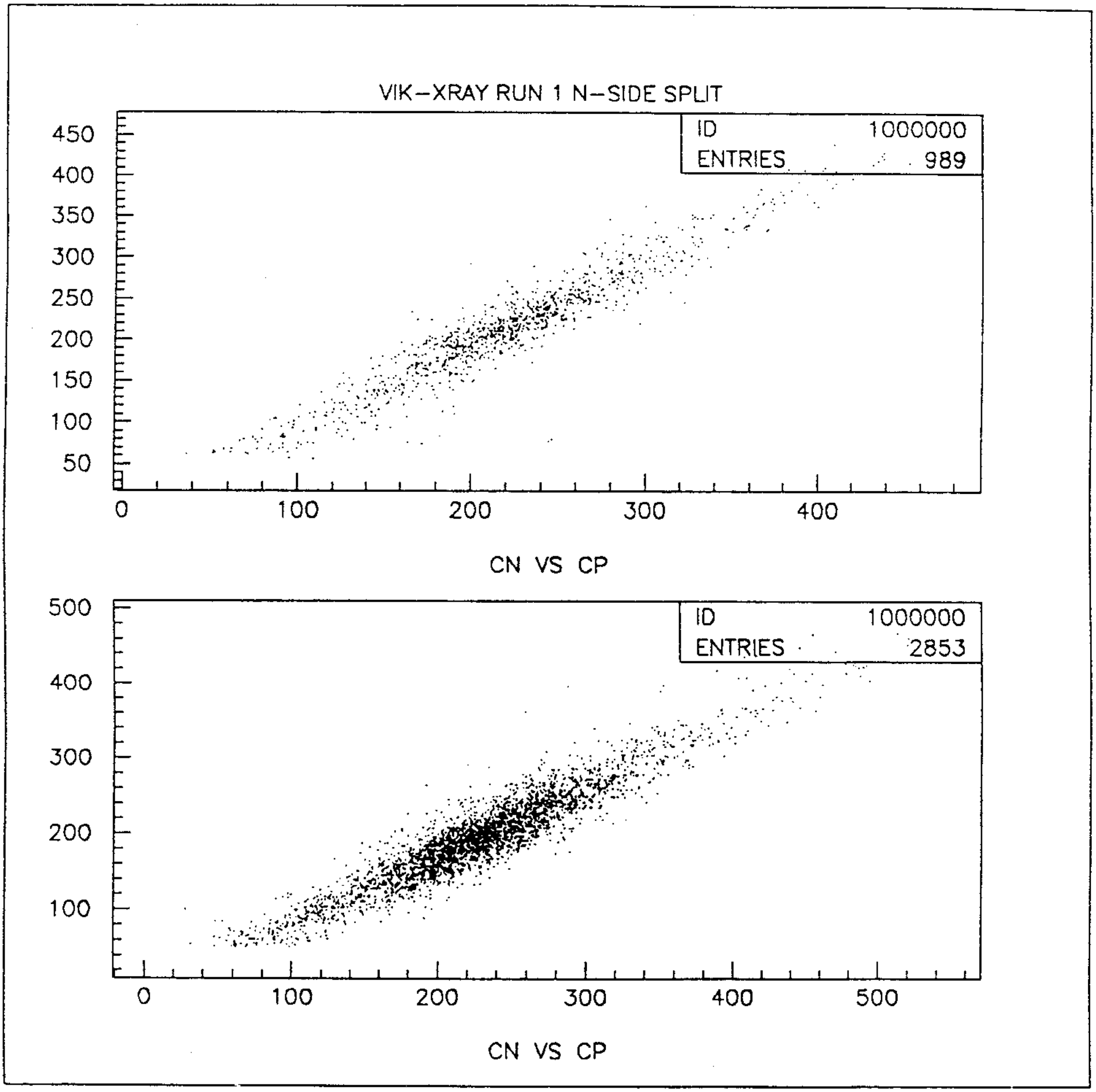
EXT -0.40 V AC
CH1 .1 V ~
CH2 .1 V ~
BWL
T/div 5 µs

Fig. 4



VIKING - ENC vs load capacitance

Fig. 5


VIK–XRAY RUN 1 N–SIDE SPLIT
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ENTRIES 989
450
400
350
300
250
200
150
100
50
0
100
200
300
400
CN VS CP
ID 1000000
ENTRIES 2853
500
400
300
200
100
0
100
200
300
400
500
CN VS CP

Fig. 6

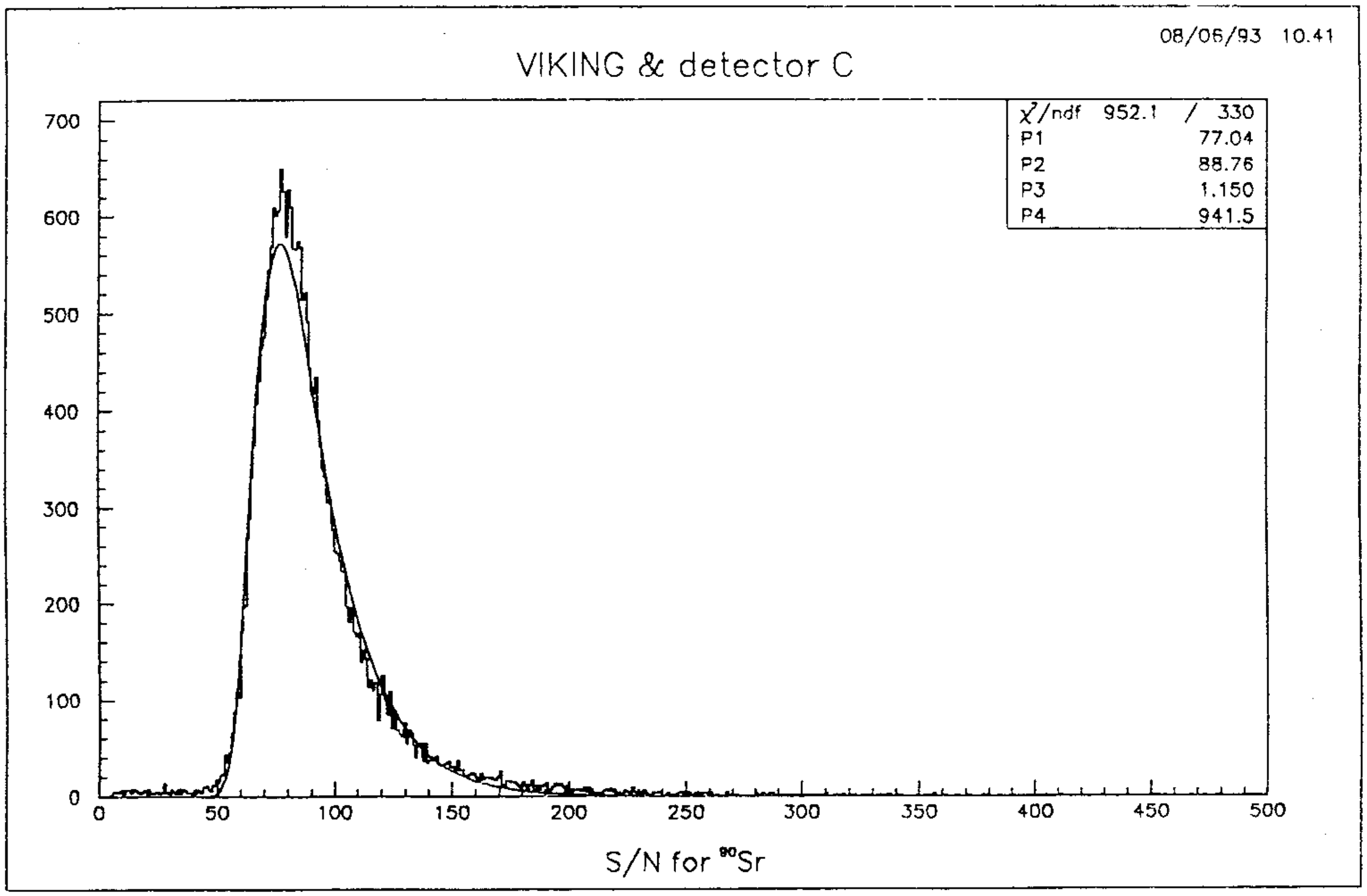
08/06/93 10.41
VIKING & detector C
χ²/ndf 952.1 / 330
P1 77.04
P2 88.76
P3 1.150
P4 941.5
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400
450
500
S/N for ⁹⁰Sr

Fig. 7

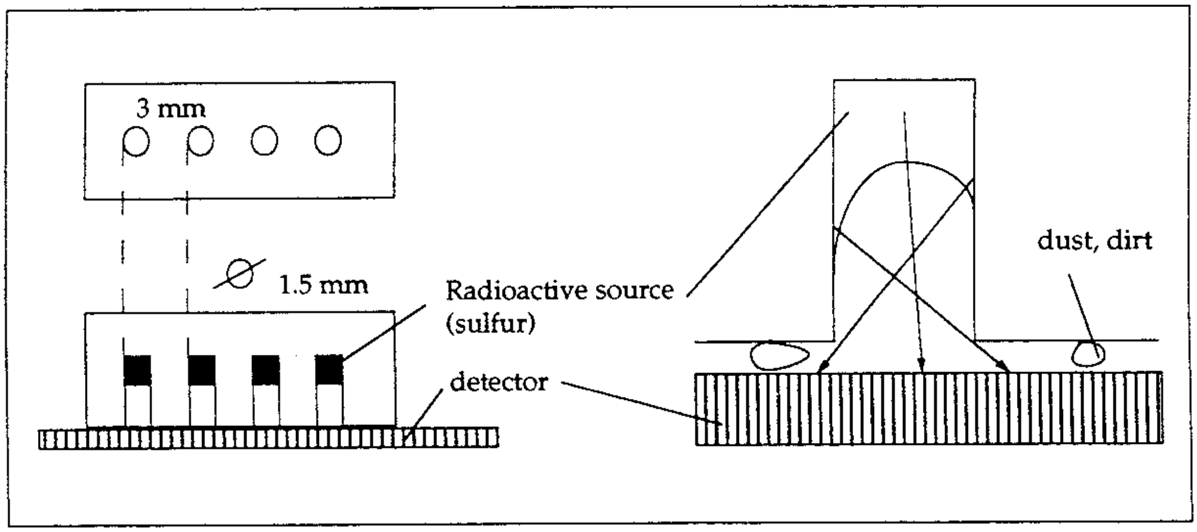
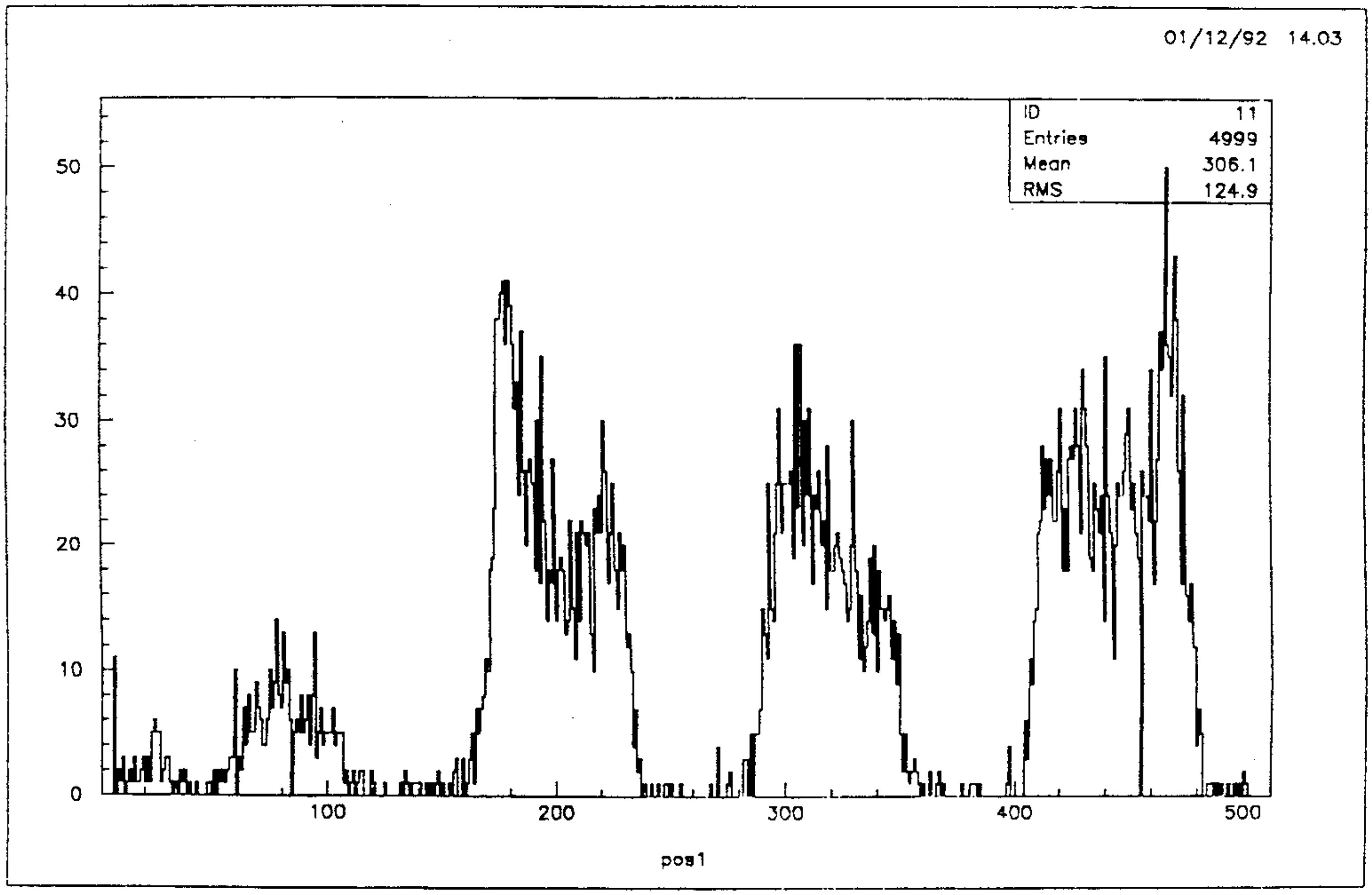


Fig. 8 a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ID 11
Entries 4999
Mean 306.1
RMS 124.9
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10
20
30
40
50
100
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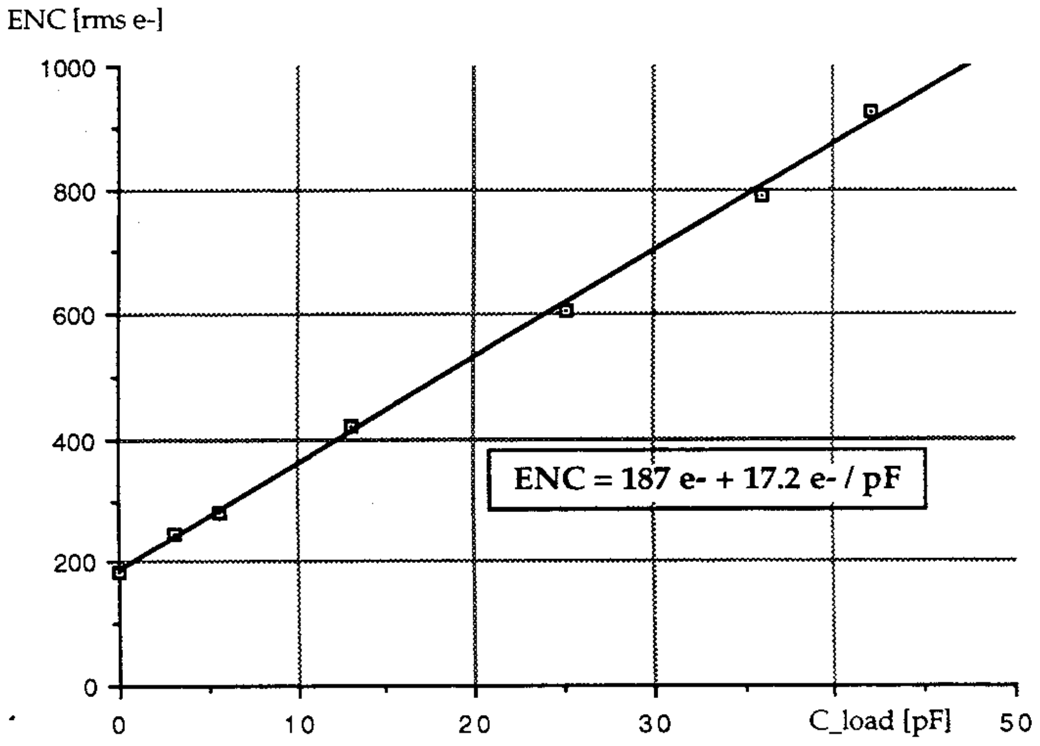
300
400
500
pos1

Fig. 8 b



Viking - ENC vs load capacitance after 50 krad e- irradiation for 2 µs shaping time

Fig. 9

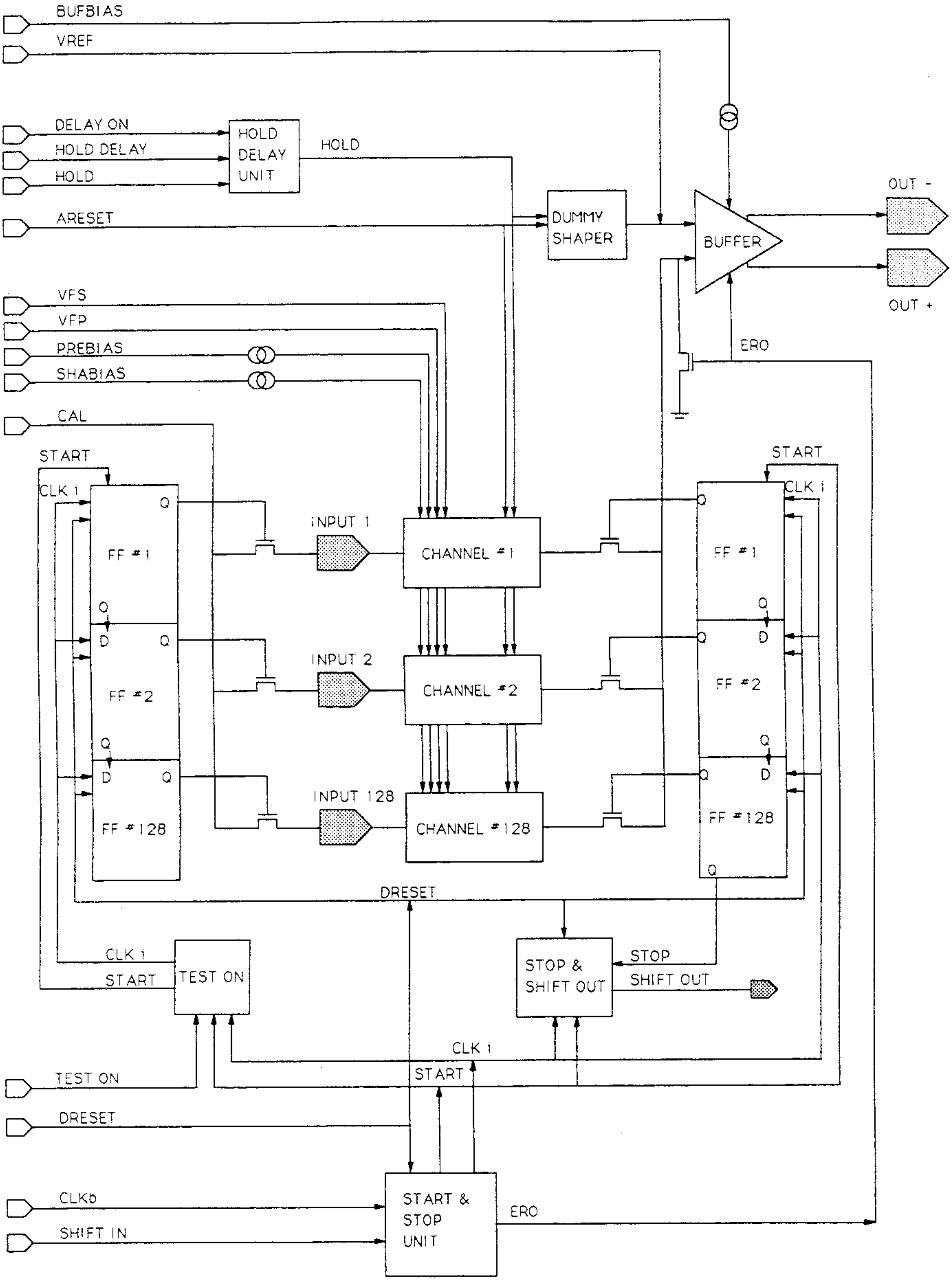

BUFBIAS
VREF
DELAY ON
HOLD DELAY
HOLD
HOLD DELAY UNIT
HOLD
ARESET
DUMMY SHAPER
BUFFER
OUT -
OUT +
ERO
VFS
VFP
PREBIAS
SHABIAS
CAL
START
CLK i
Q
FF #1
D
Q
FF #2
Q
D
Q
FF #128
INPUT 1
CHANNEL #1
INPUT 2
CHANNEL #2
INPUT 128
CHANNEL #128
START
CLK i
Q
FF #1
Q
D
FF #2
Q
D
FF #128
Q
DRESET
CLK i
START
TEST ON
STOP & SHIFT OUT
STOP
SHIFT OUT
CLK i
START
TEST ON
DRESET
CLKb
SHIFT IN
START & STOP UNIT
ERO

Fig. 10