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Physikalisches Institut

A "Bioscope" system using double-sided silicon strip detectors and self-triggering read-out chips*

M. Overdick [d], A. Czermak [e], P. Fischer [d], V. Herzog [c], A. Kjensmo [b], T. Kugelmeier [d], K. Ljunggren [f], E. Nygård [b], C. Pietrzik [c], T. Schwan [d], S.-E. Strand [f], J. Straver [b], P. Weilhammer [a], N. Wermes [d], K. Yoshioka [b]

[a] *CERN, Geneva, Switzerland*
[b] *IDE AS, Oslo, Norway*
[c] *Institut für Zellbiologie der Universität Bonn, Germany*
[d] *Physikalisches Institut der Universität Bonn, Germany*
[e] *Institute for Nuclear Physics, University of Cracow, Poland*
[f] *Radiation Physics Department, University of Lund, Sweden*

Abstract: The components and the design of a 640 by 640 channel radiation detection system based on double-sided silicon strip detectors and self-triggering read-out chips are presented. The system has been designed for applications in autoradiography and X-ray imaging in medicine, biology and other fields. Images and results from first tests of the system are shown.

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Post address:
Nussallee 12
D-53115 Bonn
Germany

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[a] *CERN, Geneva, Switzerland*
[b] *IDE AS, Oslo, Norway*
[c] *Department of Cell Biology, University of Bonn, Germany*
[d] *Physics Department, University of Bonn, Germany*
[e] *Institute for Nuclear Physics, University of Cracow, Poland*
[f] *Radiation Physics Department, University of Lund, Sweden*

[*] Corresponding author
Address: Physics Department, University of Bonn, Nussallee 12, D-53115 Bonn, Germany

Abstract

The components and the design of a 640 by 640 channel radiation detection system based on double-sided silicon strip detectors and self-triggering read-out chips are presented. The system has been designed for applications in autoradiography and X-ray imaging in medicine, biology and other fields. Images and results from first tests of the system are shown.

1. Introduction

Double-sided silicon microstrip detectors offer a high position and energy resolution for the detection of ionizing particles and X-rays [1]. These capabilities of the microstrip detectors and their high detection efficiency compared to photographic films suggest their use in applications such as medical and biological autoradiography, X-ray imaging in medicine, crystallography, material science and other fields. In such applications the particles enter the sensor at random times. Therefore the read-out electronics connected to the sensor needs to recognize hit events automatically, i.e. the read-out devices have to be self-triggering.

This is in contrast to the situation found in particle accelerator experiments where the timing of the particle reactions is precisely known so that the read-out electronics can be triggered by an external signal. Accelerator experiments are currently the main field of application for microstrip detectors [2,3].

Apart from the self-triggering capability the read-out electronics for microstrip detectors in non-accelerator applications have to be integrated to a high density of read-out channels. Moreover, each channel must have a very good noise performance to allow the detection of low energy X-rays ($\approx$ 10 keV) and the use of charge interpolation procedures to enhance the spatial resolution of the detector [4].

After first characterizations of a 16-channel prototype version of a self-triggering read-out chip [5], 128-channel versions have been developed, tested and improved. In this paper the Bioscope system, a complete 640 by 640 channel detector system based on the read-out chip XA1.2, is presented.

2. System components and system design

2.1 The sensor

The sensor used in the Bioscope system is a 300 μm thick double-sided silicon strip detector with a strip pitch of 50 μm on both the p- and n-sides. There are 640 strips on each side so that the sensitive area extends over 32 x 32 mm^2. The ohmic separation on the n-side is achieved by implanting 16 μm wide p-stops between the n-strips. Each of the strips is read out through a built-in capacitor (AC-coupling) consisting of the strip implants, insulating layers of oxide and nitride and a metallization layer. The strips on both sides are biased through individual poly-silicon resistors of 50 to 60 MΩ. The sensors have been manufactured by Hamamatsu.

2.2 The XA1.2 read-out chip

The XA1.2 chip is a 128 channel self-triggering chip in CMOS VLSI technology dedicated to the read-out of microstrip detectors. Like its predecessors it has been developed by IDE AS, Oslo. Its low noise pre-amplifiers and CR-RC shapers have an equivalent noise charge (ENC) of 60 e^- + $C_{load} \cdot 15$ e^-/pF at 2 μs peaking time.

The analog channel of the XA1.2 is shown schematically in Fig. 1. Depending on the polarity of the input signals an inverter can be selected (controlled by a chip-wide control bit). The amplified charge pulse is then fed both to a comparator and to a "peak store" unit. This device stores the peak value of the pulse. Once the comparator has detected a signal which is greater than an externally selected threshold, it opens the hold switch after an adjustable delay time and signals the hit to the "hit logic" of the chip. In this way a sufficiently great charge pulse at any of the 128 inputs starts the read-out cycle and the subsequent self-reset of the whole chip.

The overall architecture of the XA1.2 is shown in a simplified block diagram in Fig. 2. When an analog channel has detected a hit on the corresponding detector strip, the address of this channel will be encoded into current signals appearing on two differential output lines (*OutD1/2*). The analog pulse height of the hit channel will appear on the *AOut_Mid* output, the pulse heights of the adjacent channels on the *AOut_Top* and *AOut_Bot* outputs. (The pulse height information can be used to measure the energy deposition of the particle and to enhance the spatial resolution by means of charge interpolation.) The so-called MGO (multiplicity generator output) line indicates the hit to the electonics outside the XA1.2. This differential line delivers certain output currents depending on the number of analog channels in which the comparator threshold has been crossed within a short time interval (some nanoseconds) thus enabling to distinguish between single hit and multi hit events.

In summary it can be said that the XA1.2 performs a fully data-driven read-out cycle and only the relevant data need to be processed by the electronics outside the XA1.2 ("sparse read-out"). Up to 8 XA1.2 chips can be connected in parallel in order to read out 1024 channels. Special test modes and masking of individual channels have been implemented and are controlled by the shift register also indicated in Fig. 2.

2.3 The Bioscope system

A block diagram of the Bioscope system is shown in Fig. 3. The sensor is mounted on a double-sided hybrid (printed circuit board) which also carries 5 XA1.2 read-out chips on each side. The read-out chips are connected to the sensor and to the circuitry on the hybrid by wire bonds. The Analog Transceiver Cards supply a variety of voltages and control currents to the XA chips and amplify their output signals. In order to increase the electrical robustness and noise immunity of the system, the front-end electronics are electrically isolated from the data acquisition system by means of analog and digital opto-couplers. The Digital Transceiver Card essentially serves as a coincidence unit, i.e. it generates a trigger signal only if exactly one channel from each side has fired within an adjustable coincidence interval.

The trigger signal and the address and analog pulse height information from both detector sides is then fed into the data acquisition system, which consists of a 16-channel ADC-card controlled by a digital signal processor (DSP). The pre-processed data is transferred into the PC (which also houses the data acquisition system) for display, storage and further processing. Acquisition speeds of up to 10000 counts per second (cps) can be handled by the data acquisition system without problems, and at the moment this number is limited by the PC bus speed. The Bioscope system is entirely software-controlled ensuring user friendliness and reproducibility of the system settings.

3. First Results

Four Bisocope systems have been produced and are currently under test at Oslo, Geneva, Bonn and Lund. Some first images of β^--emitting sources acquired with the system are reproduced in Figs. 4-6.

Fig. 4 shows an autoradiogram of a broad ^{45}Ca line source prepared from a strip of filterpaper soaked with a solution containing the radio-label. The inhomegeneity in the line is mainly due to an uneven distribution of the solution in the filter paper.

An autoradiogram of two thin hairs marked with ^{35}S is shown in Fig. 5. The image was acquired over 2 hours as the activity of this sample was very low (count rate 1.5 cps). However, no background subtraction was needed although the threshold was set to an energy of approximately 10 to 15 keV. This indicates a very good noise performance of the entire detector system.

The third autoradiogram (Fig. 6) has been recorded using ^{14}C microscales (Amersham RPA.504) consisting of thin rectangular patches of different activities. The edges of these rectangles are reproduced clearly, and an analysis by means of line profiles through the image showed that the spatial resolution is well below 50 µm. For the "binary read-out" method used for generating this image (i.e. the charge distribution between the strips represented by the analog pulse heights was ignored) the theoretical resolution is $\sigma = 50\ \mu m / \sqrt{12}$. However, the fact that the electrons are emitted isotropically by the ^{14}C and that the sensor has a finite thickness lead to some washing out of the edge structures. The resolution of the system can be improved by taking into account the charge distribution between the strips, and this will be tested in further experiments.

Apart from the position localization the measurement of particle or X-ray energies is also an important feature of the Bioscope system. After establishing a preliminary procedure for the energy calibration of the individual channels, energy spectra from a variety of radio-nuclides have been recorded. The results have been used to check the linearity of the analog channels (Fig. 7).

4. Conclusions and further work

The first tests of the Bioscope system showed encouraging results with respect to stability, noise and the number of insensitive strips. Images and energy spectra from a variety of sources have been recorded with good results.

As next steps the spatial resolution of the system will be improved by using the analog pulse height information (charge interpolation). The energy resolution will also be enhanced by implementing an optimized calibration procedure. More tests with samples directly connected with applications in medicine and biology are already under way at the Universities of Lund and Bonn. Further topics pursued within the collaboration are extensions of the tradional autoradiography, namely time resolved autoradiography and autoradiography with multiple markers.

References

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Figure captions:

Fig. 1: Schematic diagram of the analog channels of the self-triggering XA1.2 read-out chip

Fig. 2: Simplified block diagram of the XA1.2 chip

Fig. 3: Block diagram showing the main components of the Bioscope system

Fig. 4: Autoradiogram of a broad ^{45}Ca line source

Fig. 5: Autoradiogram of two thin hairs labelled with ^{35}S

Fig. 6: Autoradiogram of two ^{14}C microscales

Fig. 7: Pulse heights versus energies of some characteristic points extracted from various energy spectra recorded with the Bioscope system

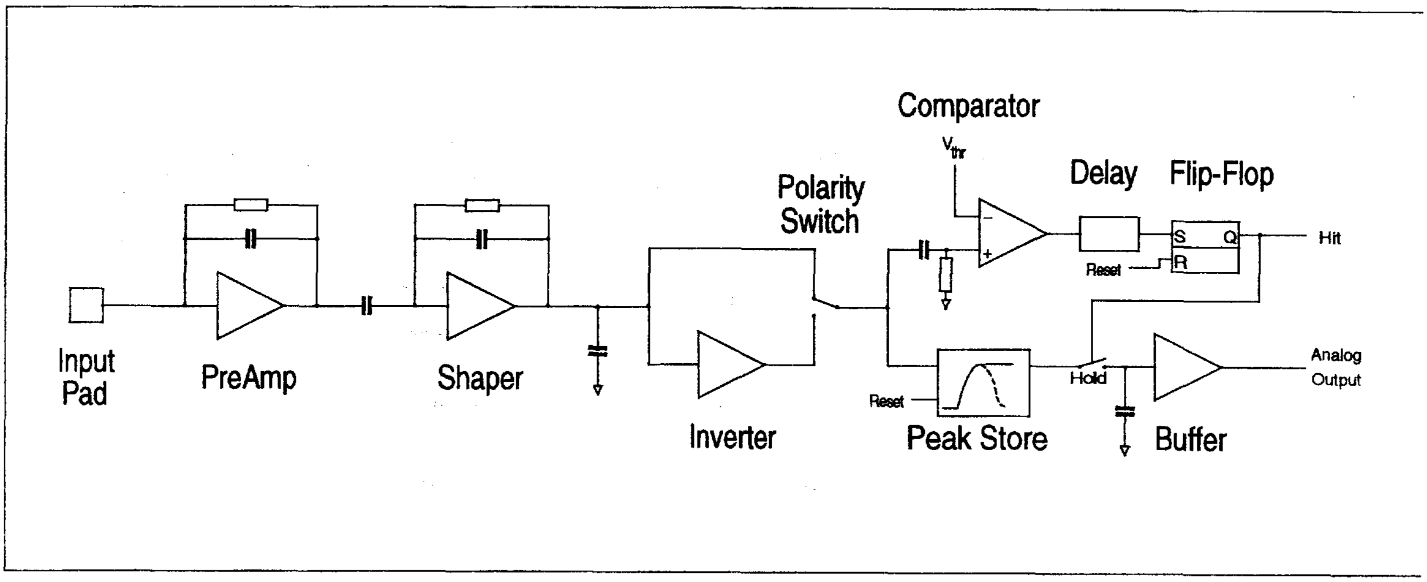

Comparator
V_{thr}
Delay
Flip-Flop
Polarity
Switch
S
Q
R
Hit
Reset
Input
Pad
PreAmp
Shaper
Inverter
Reset
Peak Store
Hold
Buffer
Analog
Output

Fig. 1

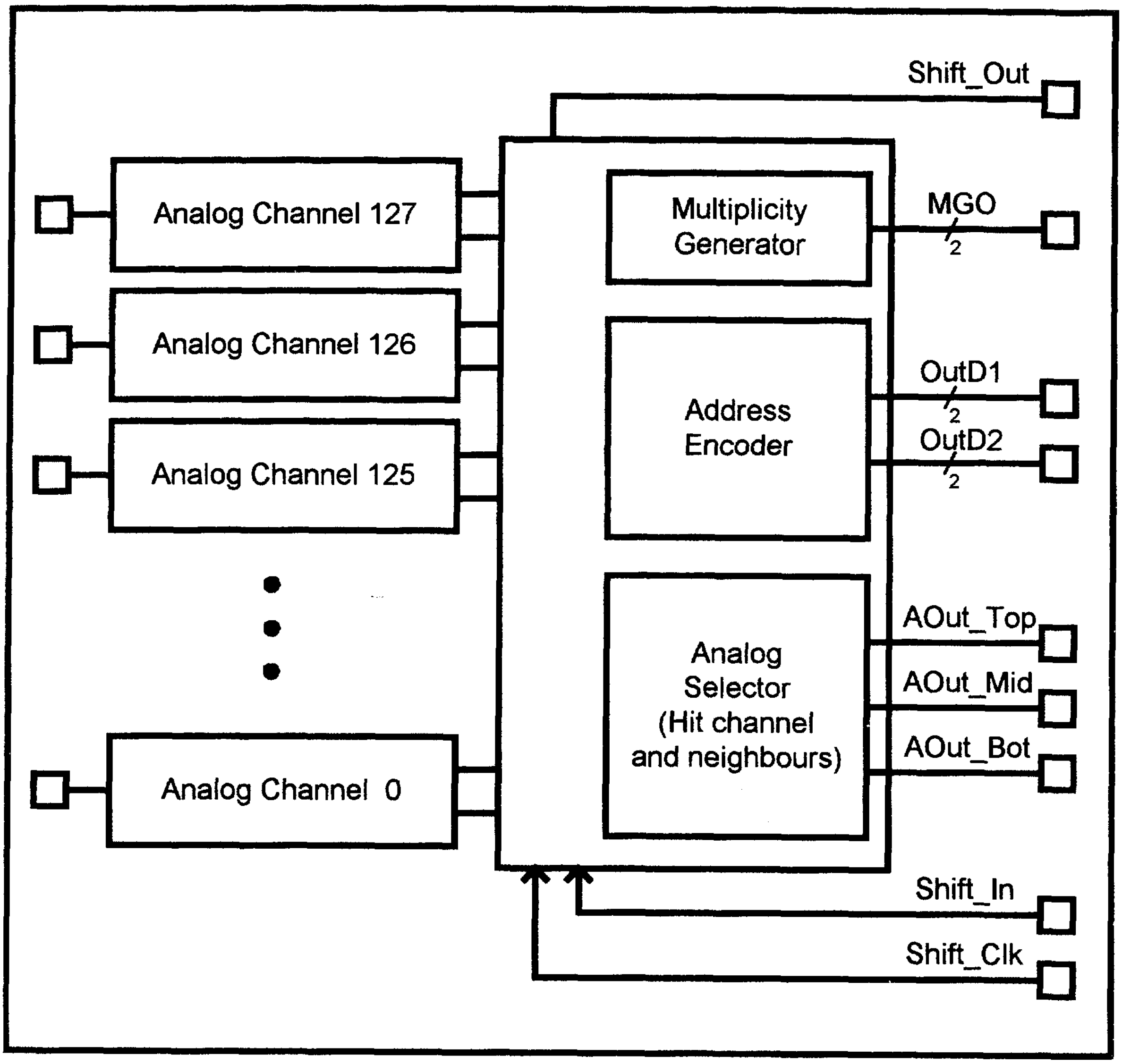

Shift_Out
Analog Channel 127
Analog Channel 126
Analog Channel 125
Analog Channel 0
Multiplicity Generator
MGO
2
Address Encoder
OutD1
2
OutD2
2
Analog Selector (Hit channel and neighbours)
AOut_Top
AOut_Mid
AOut_Bot
Shift_In
Shift_Clk

Fig. 2

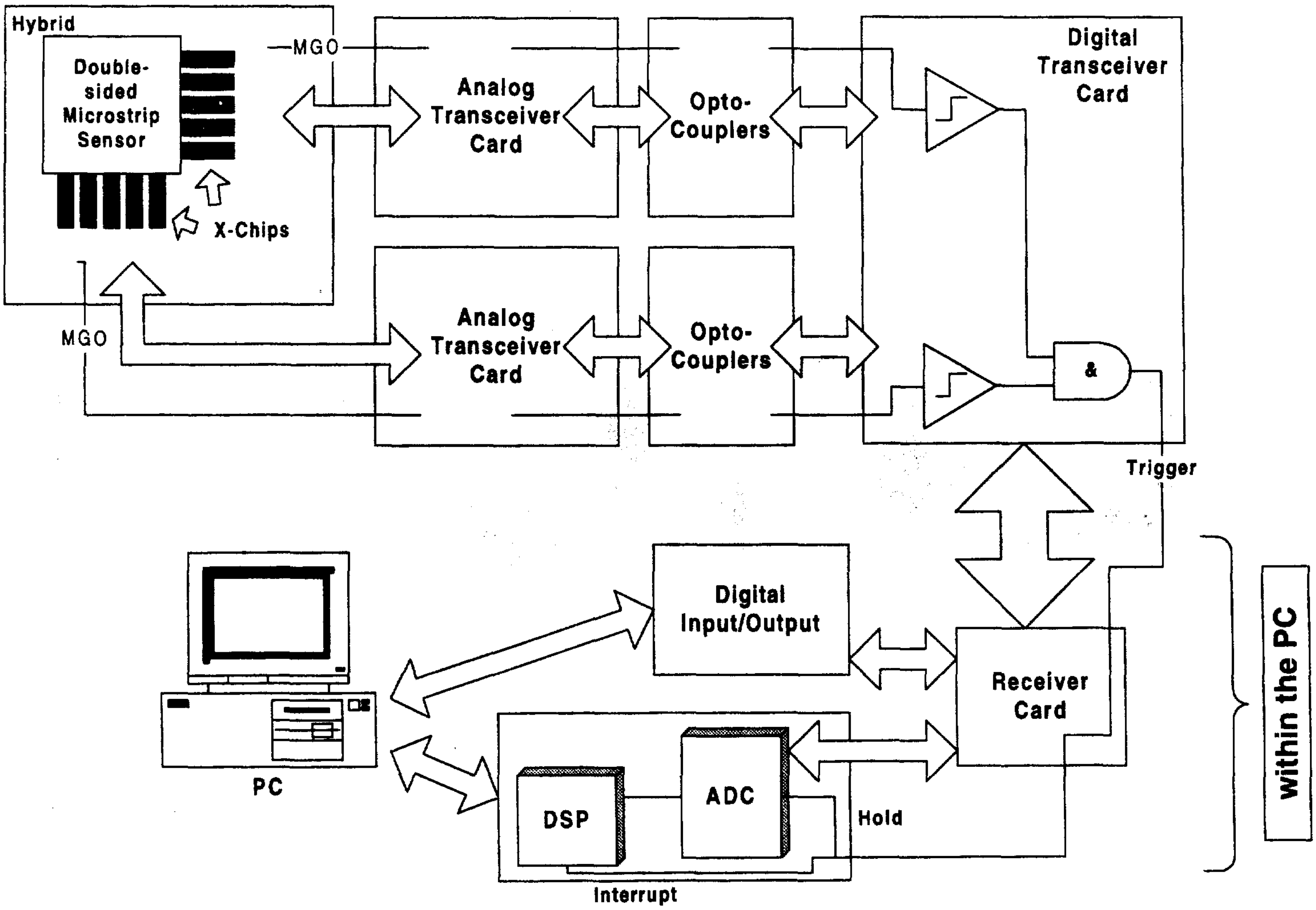

Hybrid
Double-sided Microstrip Sensor
X-Chips
MGO
MGO
Analog Transceiver Card
Analog Transceiver Card
Opto-Couplers
Opto-Couplers
Digital Transceiver Card
&
Trigger
PC
Digital Input/Output
Receiver Card
DSP
ADC
Hold
Interrupt
within the PC

Fig. 3

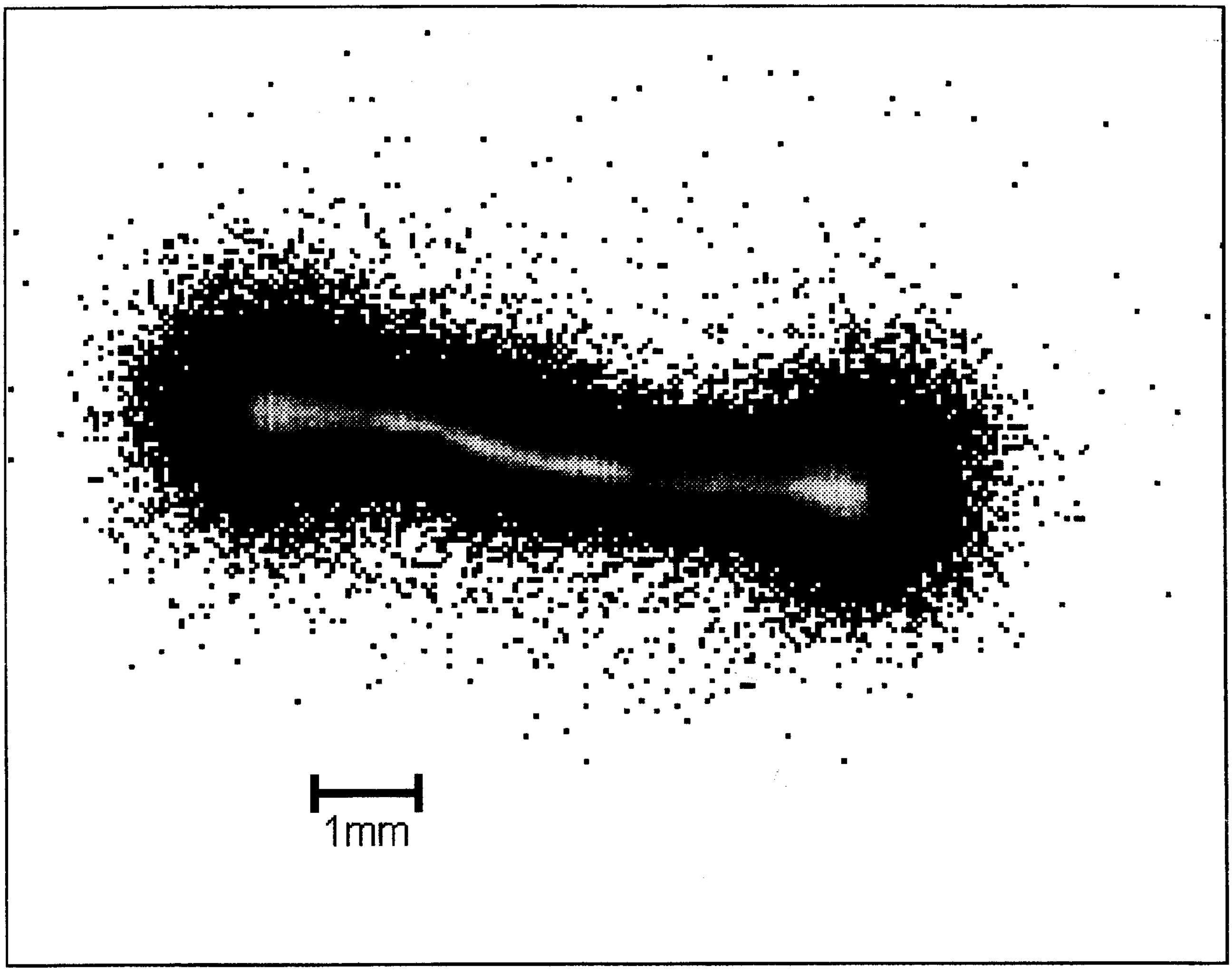


Fig. 4

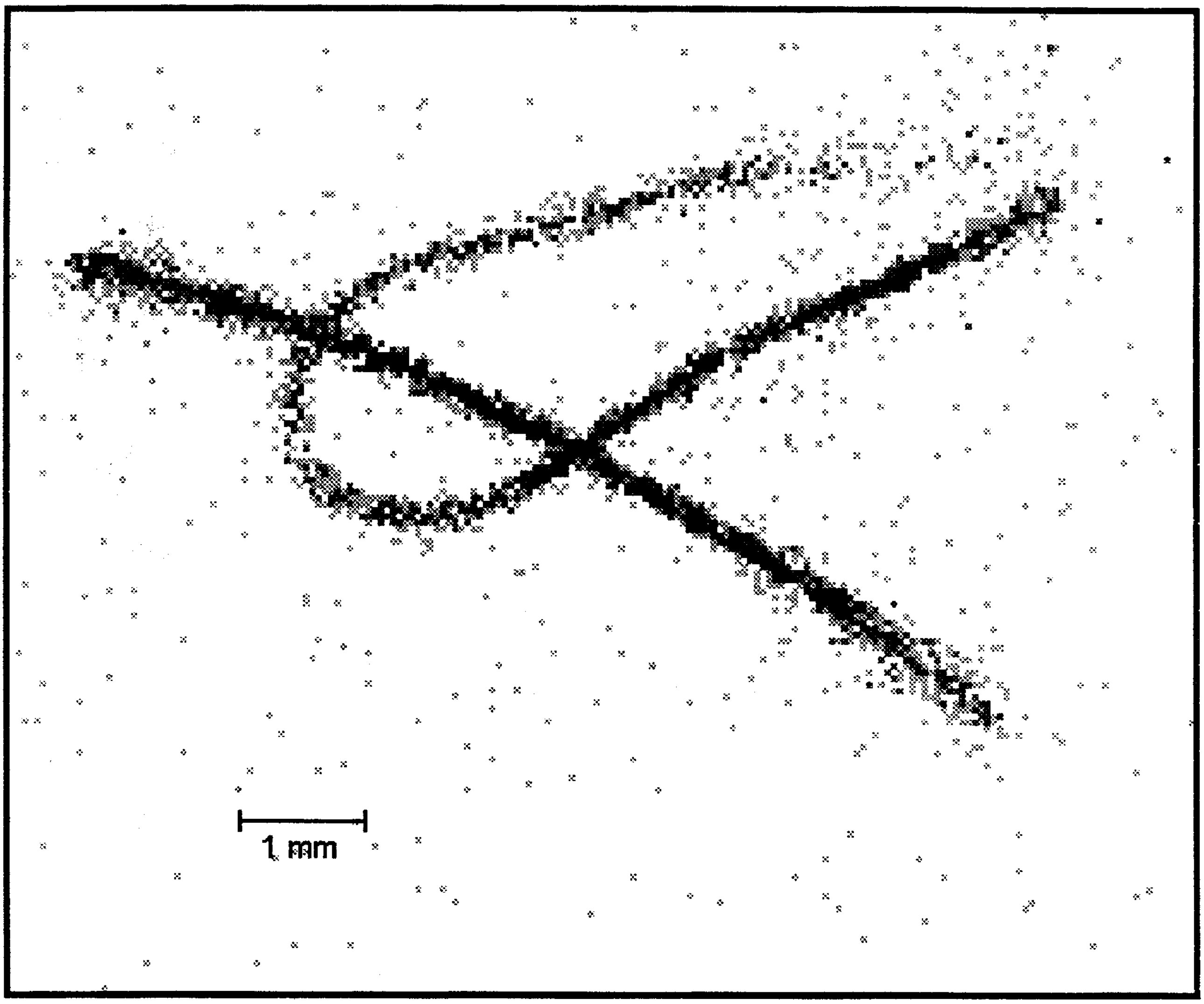


Fig. 5

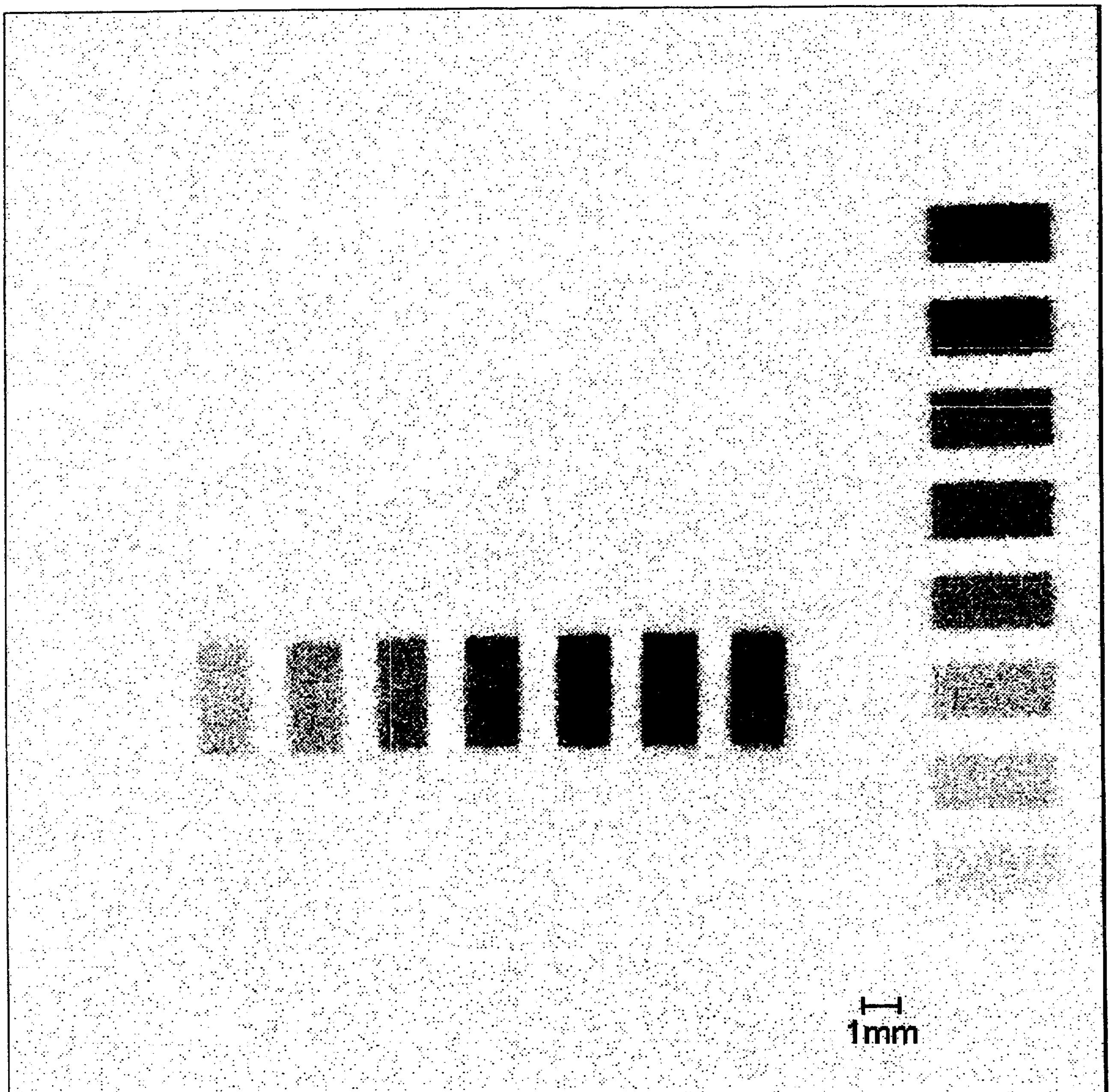
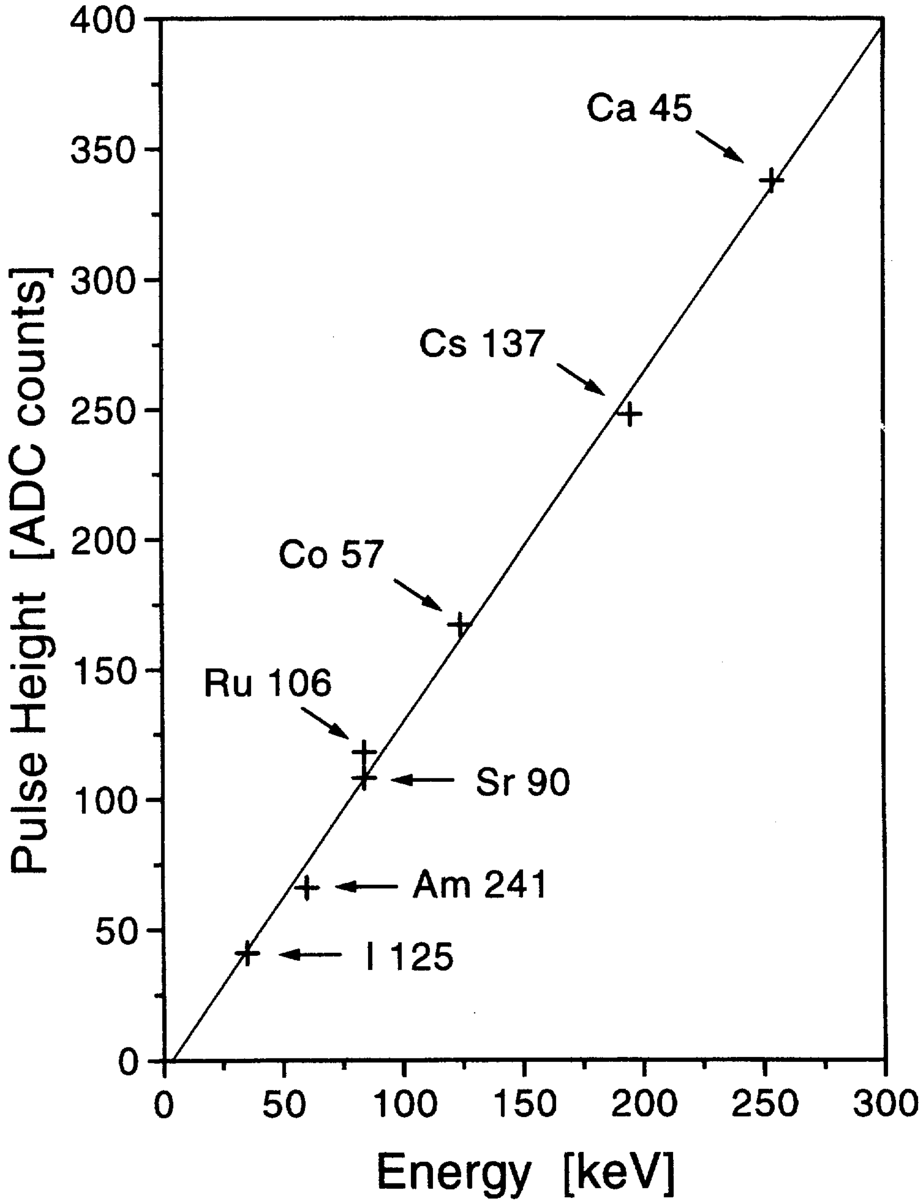


Fig. 6



Pulse Height [ADC counts]
Energy [keV]
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
Ca 45
Cs 137
Co 57
Ru 106
Sr 90
Am 241
I 125

Fig. 7