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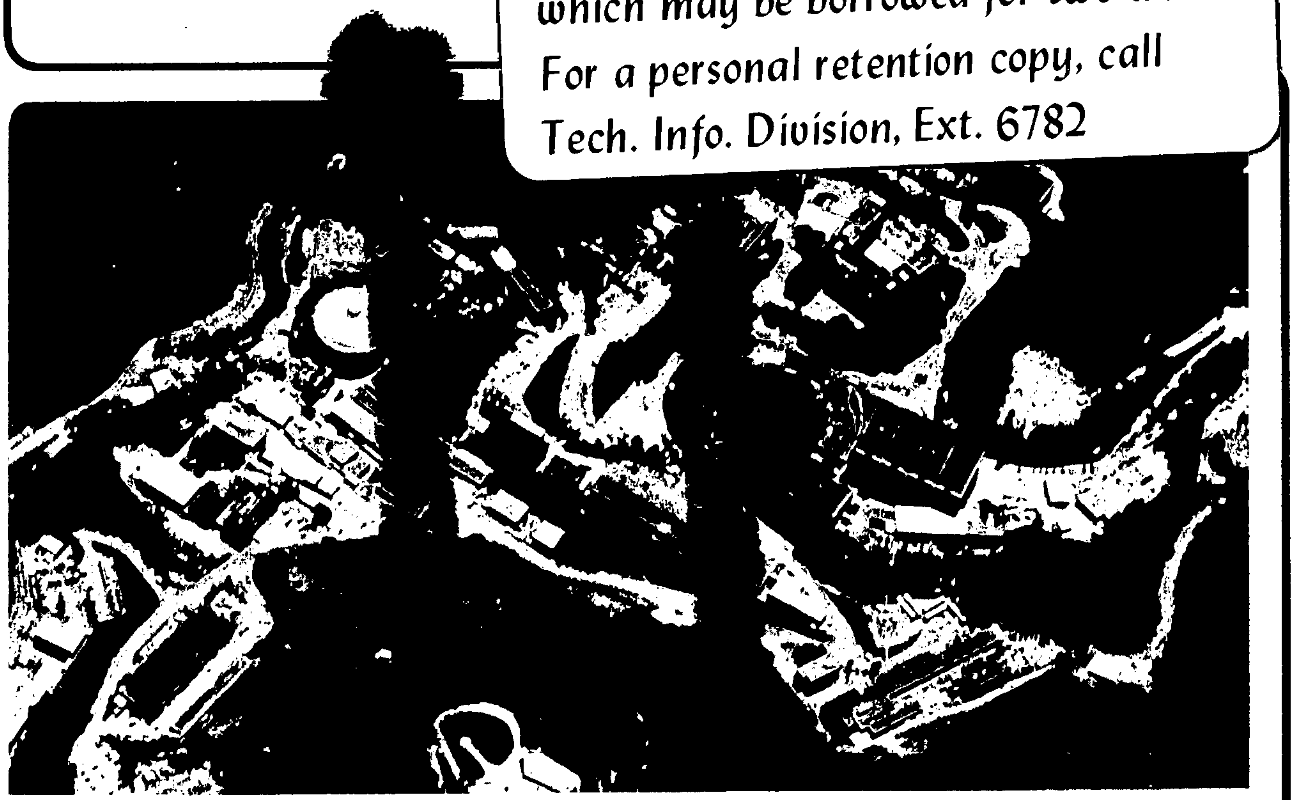

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DISCLAIMER

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DETECTION OF MINIMUM IONIZING PARTICLES WITH A CHARGE COUPLED DEVICE

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ABSTRACT

The detection of ionizing radiation using Charge-Coupled Devices is discussed. Results using a Fairchild CCD area imager are presented and its limitations examined.

I. Introduction

The use of charge-coupled devices (CCD's) as analog shift registers, optical imagers, and high density memories has been successfully demonstrated during the past ten years. CCD's are capable of very low noise operation (a S/N ratio of 1:1 with 10 electrons per pixel has been demonstrated [1]) and as imagers afford high resolution and precise image geometry and stability. The signal charge can be electrically injected into the device via an input structure, can be generated internally by photoelectric processes or, as we shall show, can result from the creation of electron-hole pairs by energetic charged particles.

Basically a CCD is a metal-oxide-semiconductor (MOS) structure forming an array of capacitors. The MOS capacitors are capable of collecting and storing in discrete packets (buckets) charge that has been "injected" into the device by one or more of the mechanisms described above. If the capacitors are packed closely together, charge stored in a particular capacitor (pixel) can be transferred to an adjacent pixel by applying clocking voltages to transfer electrodes. In this fashion charge collected at any one pixel may be moved to an output structure on the CCD device and an analog signal proportional to the charge stored at that site may be obtained. For a complete discussion of the CCD concept and device implementation we refer the reader to the literature.[2,3]

II. A CCD Area Array Detector

It has already been reported[4-5] that cooled optical CCD's are sensitive to the passage of charged particles. In fact in long exposures for some optical astronomy observations cosmic rays present a significant background problem. If we assume that a minimum ionizing particle penetrates a CCD, the amount of charge collected within the depletion region (typically 10 microns) is:

$$[2.33 g/cm^3 \times 1.66\ MeV/g/cm^2 \times 10^{-3} cm \times (3.81\ eV/e^-)^{-1}] = 1070\ electrons.$$ [6]

A S/N ratio of 20:1 is therefore obtainable for minimum ionizing events using many commercial CCD's, provided that they are cooled.

A. Fairchild 202

1. Operational Characteristics

Our current work involves the Fairchild 202 CCD, a 100×100-element interline transfer area imager. (See Figure 1). The device utilizes two phase buried channel technology in a $30\ \mu m \times 40\ \mu m$ cell format. The readout is parallel/serial to an on chip amplifier.

The readout rate used for our measurements was 100 kHz. Video processing consisted of a differential amplifier stage with a gain of 50 followed by a double correlated sample and hold. (Figure 2) An optical setup projected a standard TV bar pattern resolution chart (Figure 3) onto the CCD and was used for clock driver optimization.

2. Sr^{90} Exposure

The CCD was mounted in a cryostat (Figure 4) and operated at temperatures between 145°-210°K. The 202 was then exposed to a Sr^{90} source and read out continuously at the 100 kHz pixel rate. Figure 5 shows the CCD output displayed on a video monitor showing single hits due to beta's from the Sr^{90} source. Each dot in Figure 5 represents a single pixel with a spatial resolution of 30 μm × 40 μm. The CCD output was also sent to a multichannel analyzer in order to obtain the pulse height spectrum from the CCD. Figure 6 shows the pulse height spectrum obtained from a 2 hour Sr^{90} exposure. The 202 has a depletion depth of 7 μm ± 1 μm; therefore, for a minimum ionizing particle we would expect approximately 700 electrons. From Figure 6 the most probable value for energy loss is approximately 610 electrons. The mean value is channel 280 corresponding to 1050 electrons. The spectrum exhibits a typical Landau tail and has a most probable value agreeing quite well with what we would expect for a 6 μm-8 μm depletion depth. The measured rms noise from the 202/processor system was 200-250 electrons. A threshold cut at channel 120 was used to obtain Figure 6. The detection efficiency for the 202 system average over a number of runs was measured to be 50%-60%. This measurement was accomplished by masking off a thick scintillator to give a 3 mm × 4 mm window corresponding to the active (sensitive) area of the 202. We then placed the scintillator in the same geometric relationship to the source as was done with the 202 and measured the count rate (window open) - count rate (window closed). This number was defined as the 100% efficient count rate to which the CCD rate was compared. The CCD efficiency number was limited by the relatively high noise value we obtained for this chip which was due in part to our clock driver electronics and in part to a relatively high noise value for the particular 202 chip we were using. An optical system using a 202 CCD has reported[7)] a noise figure of 30 electrons and we believe this number is more indicative of the noise characteristics that are obtainable with the 202.

B. Limitations and Conclusions

Although our detection efficiency was limited to 60%, we do not believe that this is a basic limitation of CCD devices in general or of the 202 in particular. With low noise driving electronics we believe that nearly 100% detection efficiency for minimum ionizing particles is possible with a number of commercially available optical CCD's. However, due to the fact that not all the area of a typical CCD chip is sensitive (due to bonding pads etc.), the overall detection efficiency will be limited by the chip geometry if the entire physical area of the CCD chip is considered.

The problem of radiation damage for most CCD's is still a serious one, however. At exposure levels of 10^4 RADS multiple phase CCD's have demonstrated an increase in dark current of a factor of 20. Performance variations of this magnitude would have serious consequences for CCD's used in High Energy Physics Experiments. However, Texas Instruments has developed a new CCD technology using a single clock for charge transfer and devices built using this technology have shown little radiation damage at exposure levels up to 10^5 RADS.[8)]

Our general conclusion is that emerging commercial CCD technology is producing devices that will be able to detect minimum ionizing particles with nearly 100% efficiency within the chips active area. In addition, the radiation hardness of some of these devices appears to make them useful as detectors for High Energy Physics Experiments. These devices present great promise as high resolution vertex detectors in experiments where the cross sectional area of the CCD system does not have to be excessively large.

We would like to thank Professor Tom O'Halloran of the University of Illinois High Energy Physics Group for the loan of the Fairchild 202 CCD.

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics,Division of High Energy Physics of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

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7. Op. cit., Meyer, pg. 638.
8. Janesick, J. R., Hynecek, J., and Blouke, M. M., "A Virtual Phase Imager for Galileo", SPIE Proc. Vol. 290, pg. 165.

Figure Captions

1. Functional Block Diagram for Fairchild 202. © 1976. Fairchild Semiconductor Components Group, Fairchild Camera and Instrument Corporation.
2. CCD output circuit and waveform. The correlated double sample/hold processing function is also shown.
3. Optical setup video display. The line to line spacing for the smallest set of horizontal lines is approximately 4 pixels.
4. CCD Cryostat.
5. Single hit Video Display Events from Sr^{90} beta's.
6. Pulse height spectrum for Sr^{90} beta's. Effective detector thickness CCD depletion depth = 7 microns.

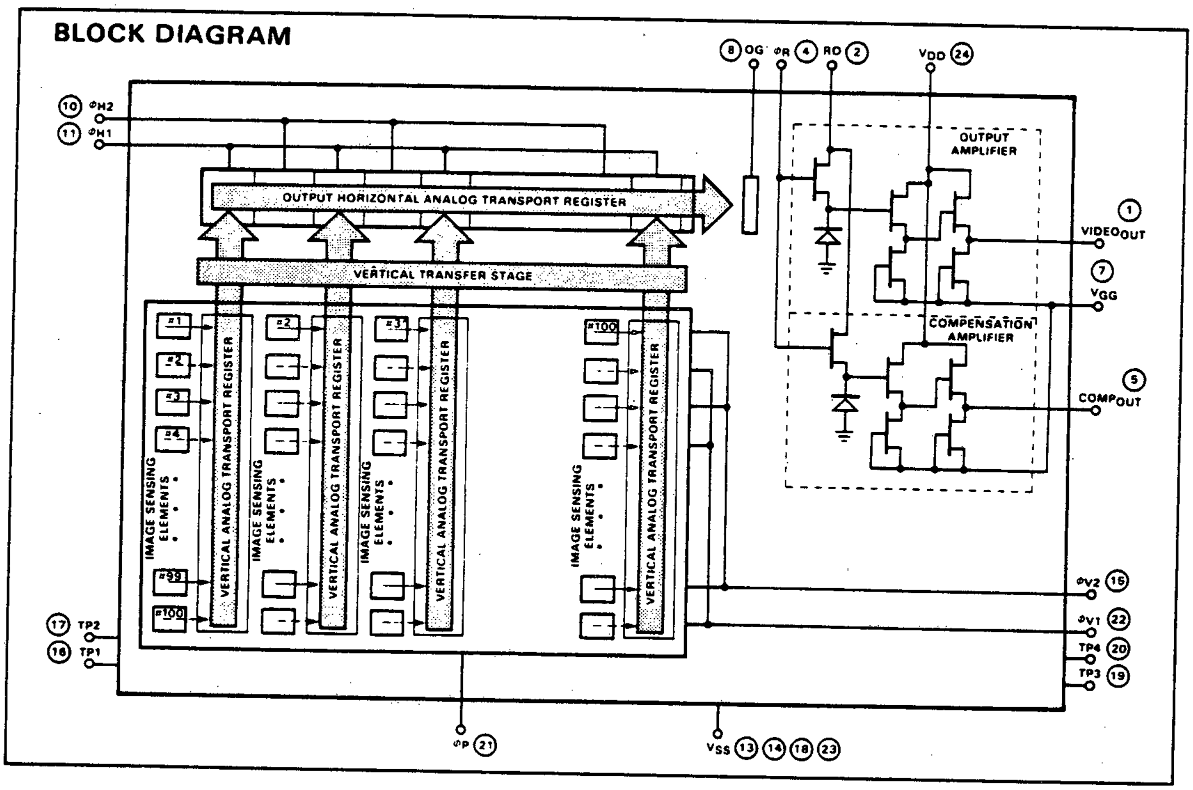

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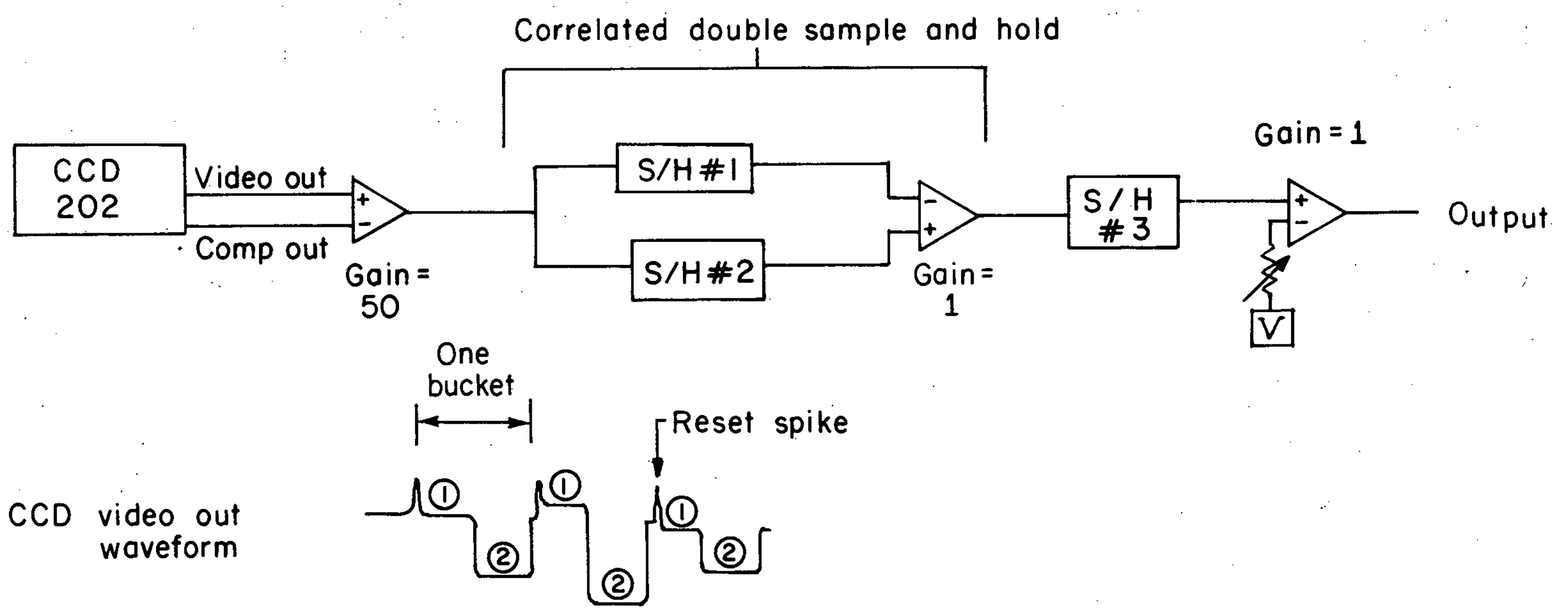
Fig. 1

Functional Block Diagram for Fairchild 202 © 1976, reproduced with permission, Fairchild Camera and Instrument Corporation, 1982



Notes: Level 1 is reset level
Level 2 is signal level + reset level
Output = 2 − 1, thus eliminating reset noise
S/H #3 switches to hold mode 1 μS after S/H #2

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Fig. 2

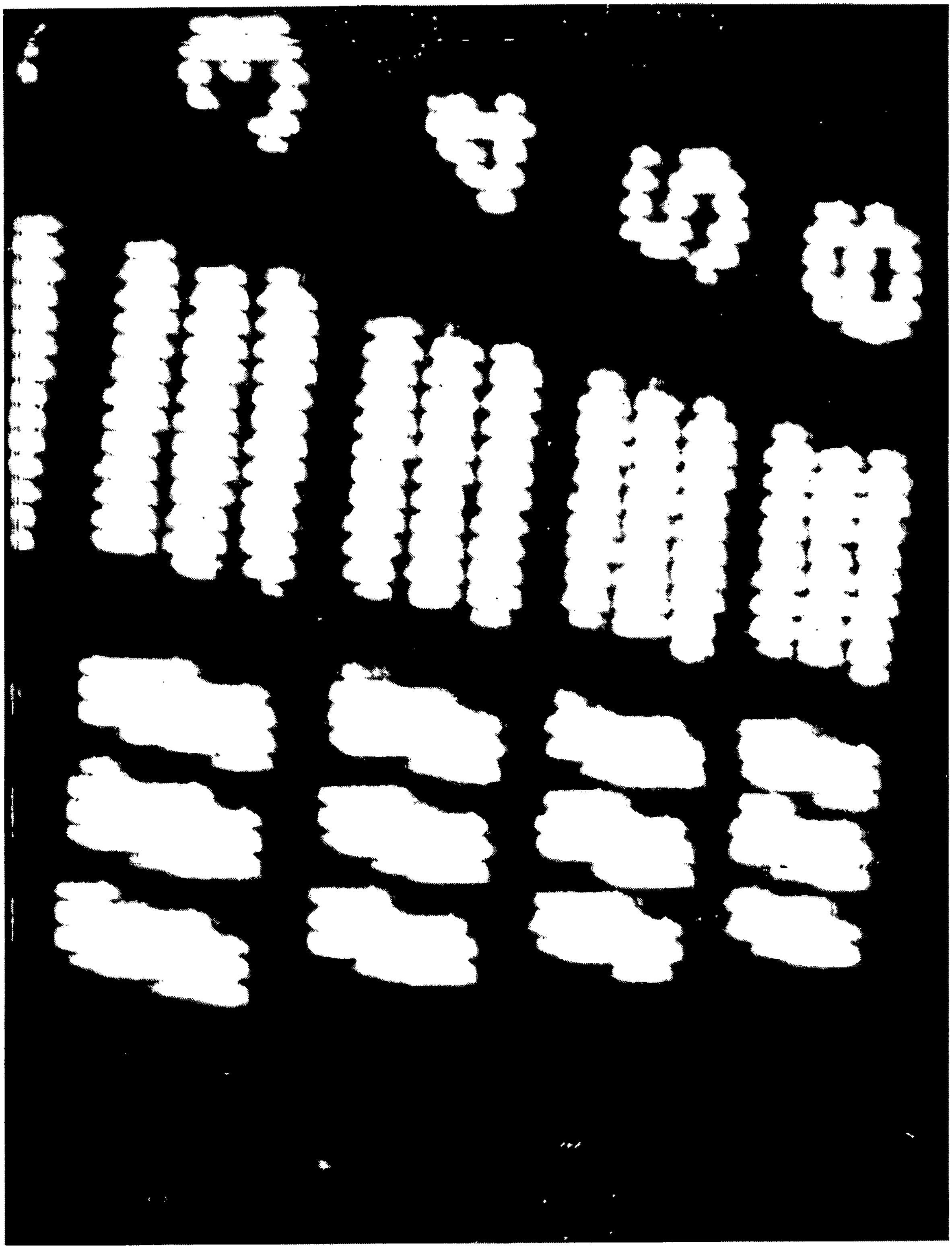

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Fig. 3

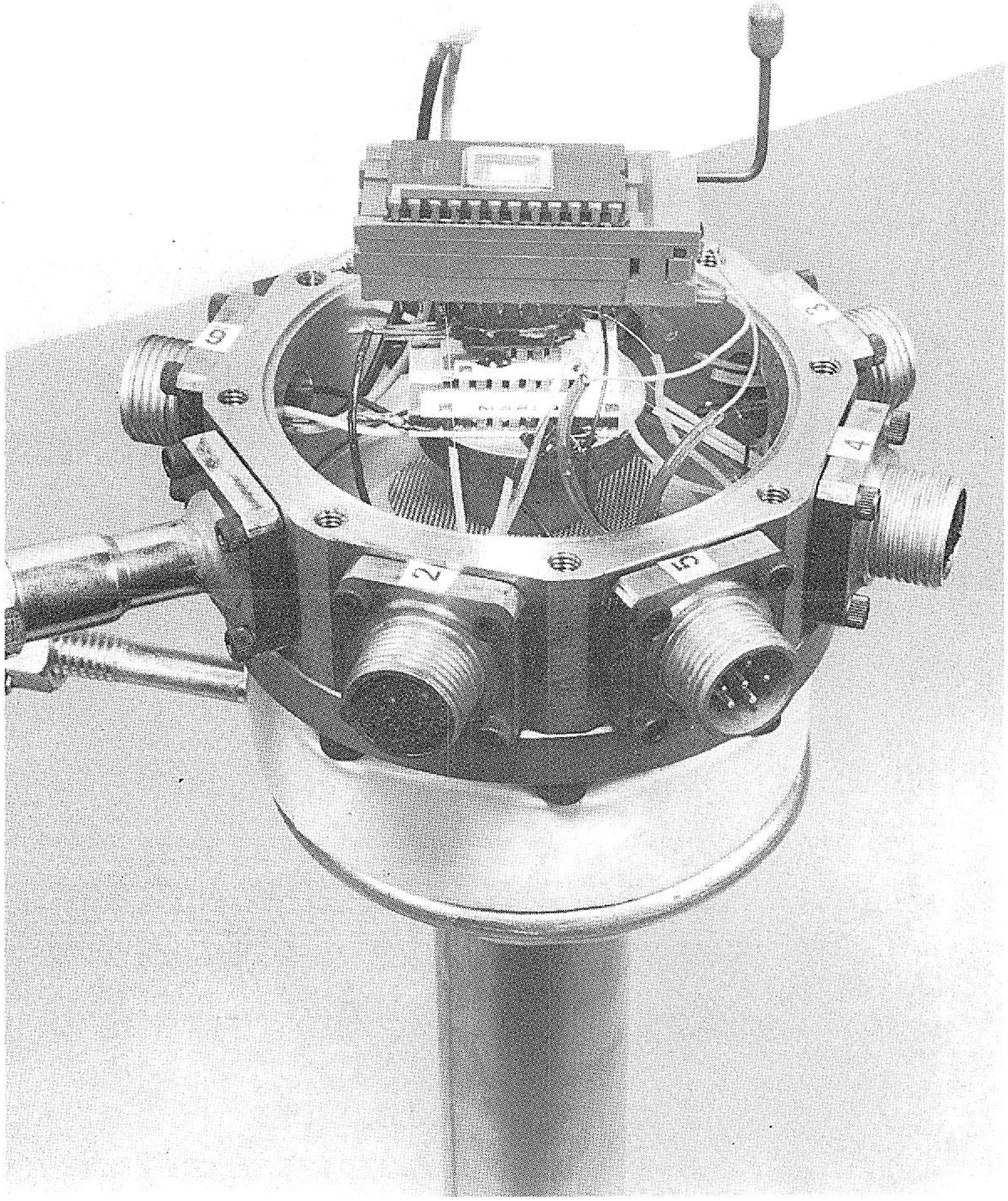

Fig. 4 CBB 810-9604

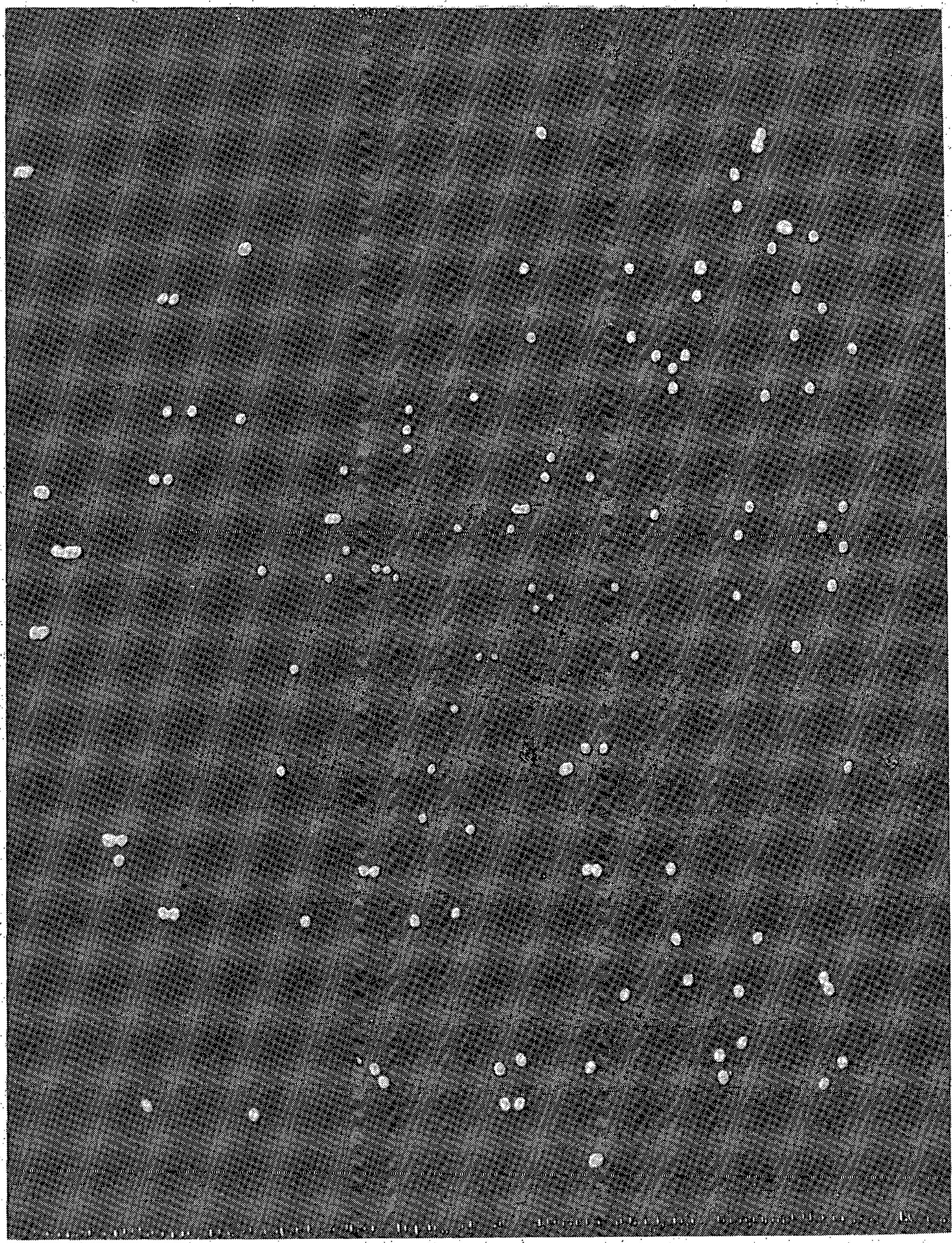

Fig. 5

XBB 810-9472

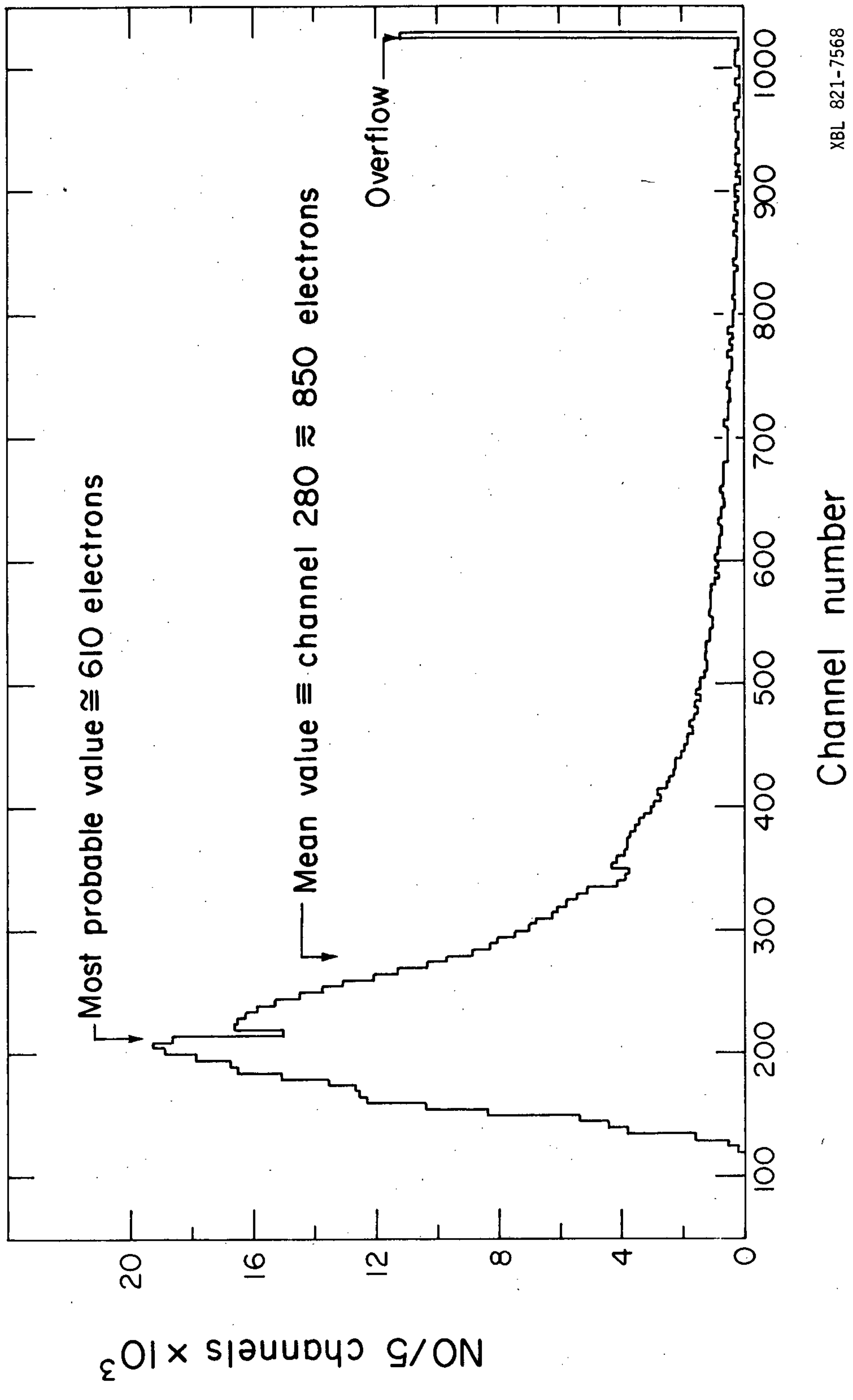
Most probable value ≅ 610 electrons
Mean value ≡ channel 280 ≅ 850 electrons
Overflow
NO/5 channels × 10^3
0
4
8
12
16
20
100
200
300
400
500
600
700
800
900
1000
Channel number
XBL 821-7568

Fig. 6

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