SLAC-PUB-1890
March 1977
(E)

RECORDING STREAMER CHAMBER TRACKS WITH CHARGE COUPLED DEVICES*

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ABSTRACT

Streamer chamber tracks have been recorded using charge coupled optical arrays. Some preliminary results regarding light sensitivity and spatial accuracy are given.

(Submitted to Nucl. Instr. and Meth.)

*Work supported by the Energy Research and Development Administration.

Introduction

Streamer chamber tracks are normally photographed with wide open lenses (typically f:2) and very fast film[1]. The resulting picture quality is sufficient to obtain high precision momentum measurement and very good multitrack resolution; however, the problem of handling large amounts of film makes filmless recording very desirable. Streamer chamber tracks have been successfully recorded by several authors using electron beam scanned tubes. In some cases such tubes have recorded very faint tracks (and therefore very short streamers) with remarkable spatial accuracy[2,3].

In the last few years charge coupled devices (CCD)[4] and charge injection devices (CID) have appeared on the market as light sensitive, self-scanning arrays. The advantages of CCD (or CID) as compared to electron beam scanned devices (Nocticon, Vidicon, etc.) are mainly in their excellent dimensional stability and the capability of operating in strong magnetic fields. However, the light sensitivity of such devices is not as high as some of the electron tubes. This is a report on our first attempt to show that CCD's are indeed sensitive enough to detect streamer tracks.

General Properties of Buried Channel CCD Arrays

The CCD (charge coupled device) chip is an array of photosensitive cells arranged in rows and columns. Two approaches to the structure of such devices have led to surface channel CCD's, and to the buried channel version, which we have used. To some extent, however, the external properties of the two structures are similar: by transferring the charge stored in each cell with appropriate clock pulses, one obtains an analog output as a series of levels very similar to the video output obtained from a conventional vidicon scanned in a raster mode.

Three sources contribute to the video output of the CCD: the light impinging each cell, the dark current leakage, and random noise. The dark current leakage varies from cell to cell, but it is repeatable from frame to frame. In this sense it is called fixed pattern. The random noise is normally less than one percent of the fixed pattern, for reading rates of 2 MHz, at room temperature.

The saturation exposure for the CCD 202A, as given by the manufacturer (table 1), is $.4 \ 10^{-6}$ Joules/cm^2, at peak sensitivity. The light intensity from streamer chamber tracks estimated from photographic image density is about $.01 \ 10^{-6}$ Joules/cm^2. There is another factor to be taken into consideration, i.e., the wave length of streamer light is 5800 A, not at the sensitivity maximum of the CCD, but almost a factor of two down. Assuming that the track image is wider than the cell size, the signal expected is of the order of 1/80 of the saturation level. At this level, the fixed pattern present on the video output at room temperature precludes a clean distinction between "empty cells" and "illuminated cells." It is therefore necessary to cool the CCD array, since the leakage dark current decreases with temperature by a factor of two every 8° C. It should be pointed out that without cooling the tracks will still be visible on a conventional display screen, in spite of the fact that the amplitude associated with "illuminated" cells is buried in the fixed pattern.

CCD Camera Performance

We have focussed streamer chamber tracks on a CCD 202A (100×100 element array) using a 25 mm focal length lens, open at f:2. The tracks were produced in the two-meter SLAC streamer chamber[1)] traversed by an hadron beam (9.4 GeV/c), with a magnetic field of 4 kG. A solid state thermoelectric cooler was used to lower the temperature of the chip to about 0° C. The demagnification (real space to CCD image plane) was 160.

The block diagram of the camera is in fig. 1: free running clock pulses at a frequency of 4.5 MHz are counted by X and Y scalers; when the video output exceeds a preset threshold counting is stopped for 25 μs and the content of the two scalers, together with pulse height information is stored. In this manner one records the actual coordinates of each picture element whose charge content is above the preset threshold. During our tests the analog-to-digital converter did not perform properly, and the pulse height information was lost.

The tracks were also photographed by our conventional camera system to correlate images as seen by the CCD camera to the actual image. Two events as recorded by CCD and film are in figs. 2 and 3. These tracks have been selected to show typical problems we have encountered: if the threshold is set at a level sufficiently low to digitize the tracks, some dark current effects appear at the bottom and at the beginning of the array (vertical line). At an even lower setting more background is seen, as in fig. 3. The two images of fig. 2 do appear different because the event was seen from two different angles. The fiducial crosses are flashed a few milliseconds after the CCD array is scanned, and therefore are not detected.

Since the curvature of the tracks in the field of view of the CCD camera is negligible, we have fitted the recorded tracks with a straight line, and plotted the residuals in fig. 4. The width of the distribution appears to be .5 cells wide (FWHM), or 7.5 microns on the image plane.

Future Plans

These preliminary tests have given us an idea of what direction to take in the next refined version of a CCD camera to be used with a streamer chamber. The use of larger arrays, like the CCD 211, should improve spatial accuracy, since the demagnification real space to image plane can be reduced. This array has higher sensitivity, and by cooling it at a temperature lower than 0^{o} C it should be possible to minimize the problem of fixed pattern. The fixed pattern can be removed in any case by subtracting it from every event seen. We are presently adding the capability of recording the fixed pattern over the full field, and modifying the cooling of the chip to reach, hopefully, -20^{o} C.

There is one problem that requires more investigation, i.e., the need of an extremely large dynamic range of the light detector: tracks produced at a small (less than 30^{o}) angle to the electric field go in a spark mode, producing a brightness a few thousand times higher than streamer tracks. Appropriate antihalation layers have reduced to some extent the problem of image blooming when using film[1)].

We have roughly measured (just by looking at the video output on a scope) the streamer brightness to be about $5\ 10^{-3}$ times the saturation level. This last number must be considered as an order of magnitude only, due to the difficulty of "measuring" a small signal added to a confusing fixed pattern; given all uncertainties, this number agrees with the 1/80 we estimated from film sensitivity and specifications of the CCD 202A. The intensity of spark tracks will be therefore about ten times saturation, sufficient to bloom a column of adjacent elements completely*: indeed we have observed this effect a few times during actual running with the streamer chamber.

Conclusions

A preliminary attempt to digitize the position of streamer chamber tracks has yielded encouraging results. By using larger arrays (like the CCD 211, 244×190 elements), smaller demagnification, and by weighting the measured

*It should be mentioned that CID (charge injection devices) have a greater tolerance to overexposure than CCD. Tests are in progress to evaluate such devices.[5]

points with the amplitude information (corrected for fixed pattern) it should be possible to obtain a level of accuracy comparable, or perhaps better, than the accuracy currently achieved with conventional film.

Acknowledgment

We wish to thank R. F. Rosche for his invaluable effort in fabricating and testing the CCD scanning logic.

References

1) F. Villa, 1973 Proceedings of International Conference on Instrumentation for High Energy Physics, Frascati, Italy, pp. 118-124.

2) J. Badier et al., Nucl. Instr. and Meth. 127 (1975) 487-494.

3) F. Cesaroni et al., 1973 Proceedings of International Conference on Instrumentation for High Energy Physics, Frascati, Italy.

4) 1975 International Conference on the Application of Charge Coupled Devices, sponsored by Naval Electronics Laboratory Center, San Diego, California 92152.

5) J. Chapman, private communication.

Table 1

	CCD 202[a)]	CCD 211[a)]
Saturation exposure	0.4 $\mu J/cm^2$	0.2 $\mu J/cm^2$
Dynamic range (typical)	300	300
Cell size	30 × 14 microns	18 × 14 microns
Clock rate (typical)	2 MHz	7 MHz
Number of cells	100 × 100	244 × 190

a) Manufactured by Fairchild Camera and Instrument Corporation.

Figure Captions

1. Electronic block diagram.
2. Tracks as seen by conventional photography and CCD 202A, reproduced to approximately the same scale.
3. Tracks as seen by conventional photography and CCD 202A, reproduced to approximately the same scale. Notice the much larger background at the bottom.
4. Deviation (in units of 1 cell size) between the best straight line fit and coordinates as measured on the CCD array.

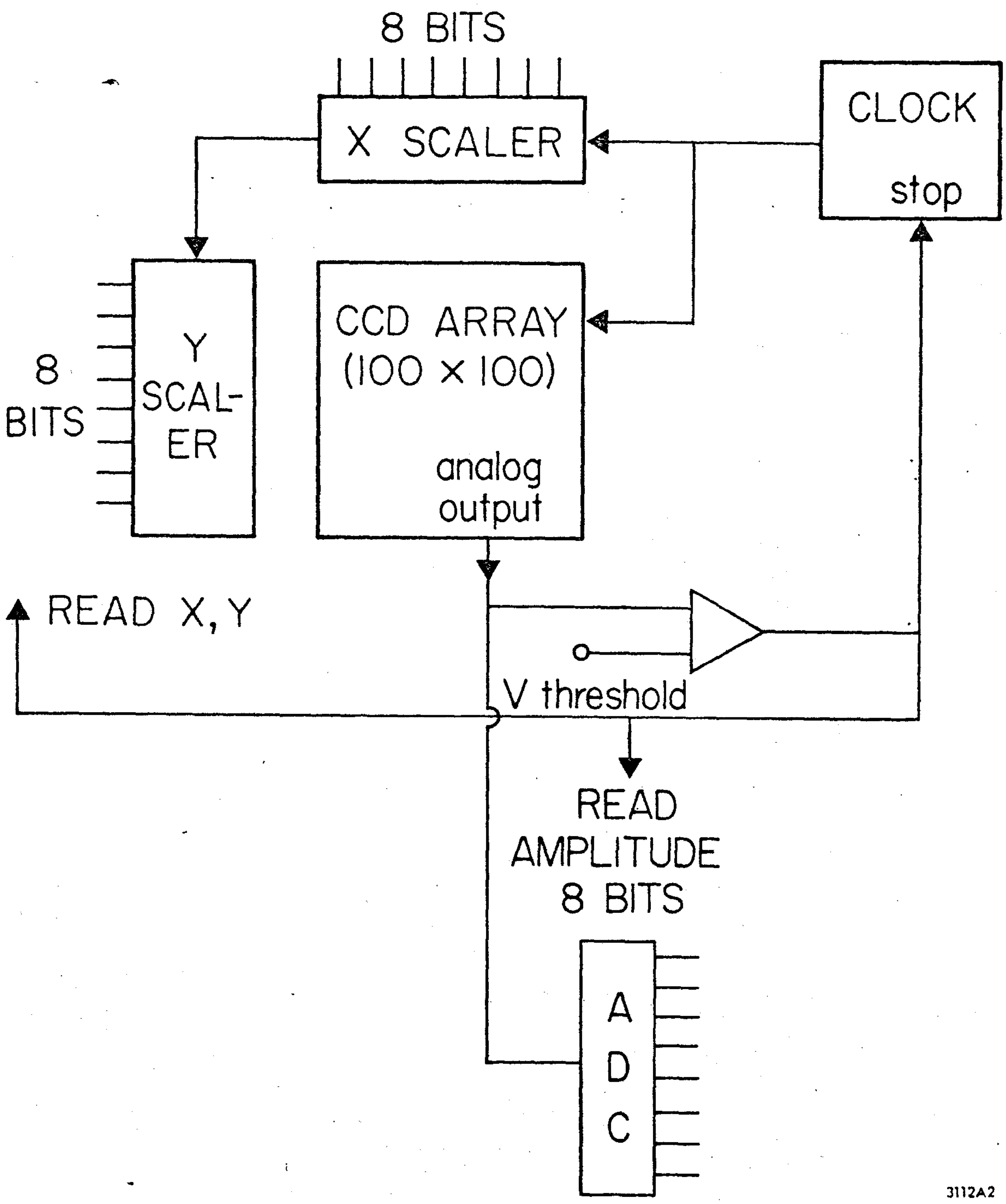
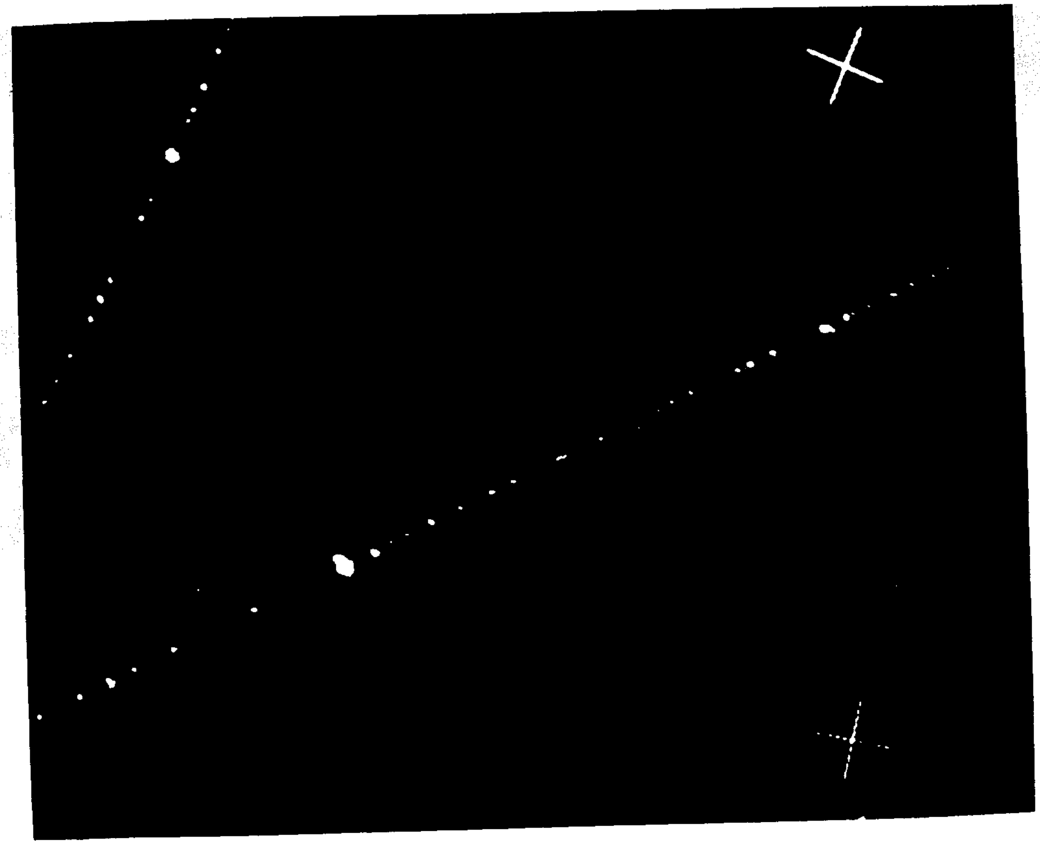
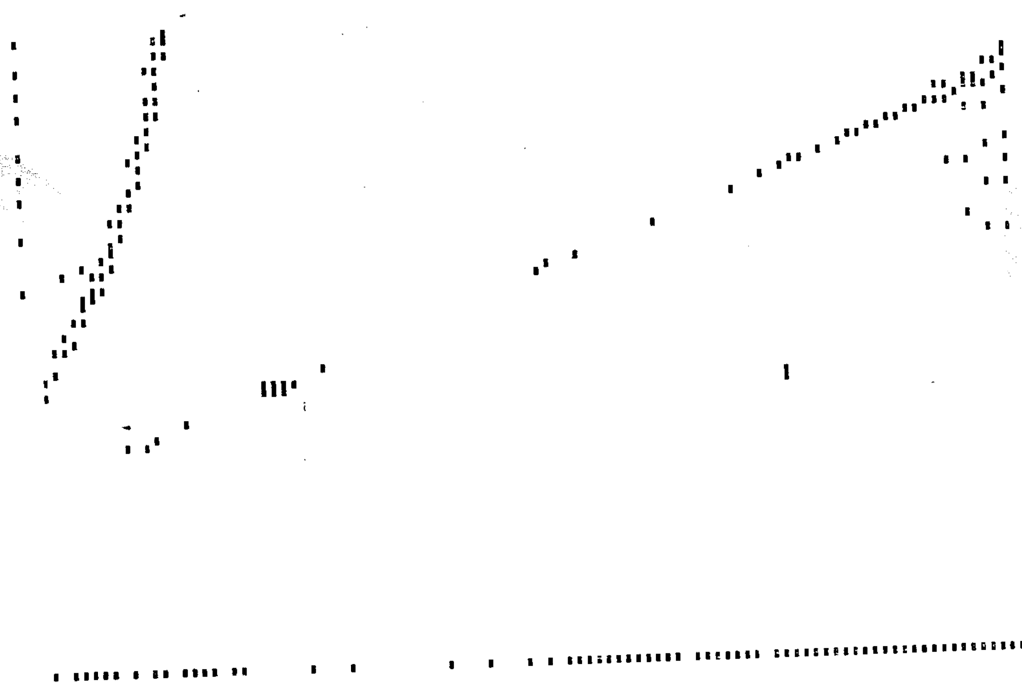
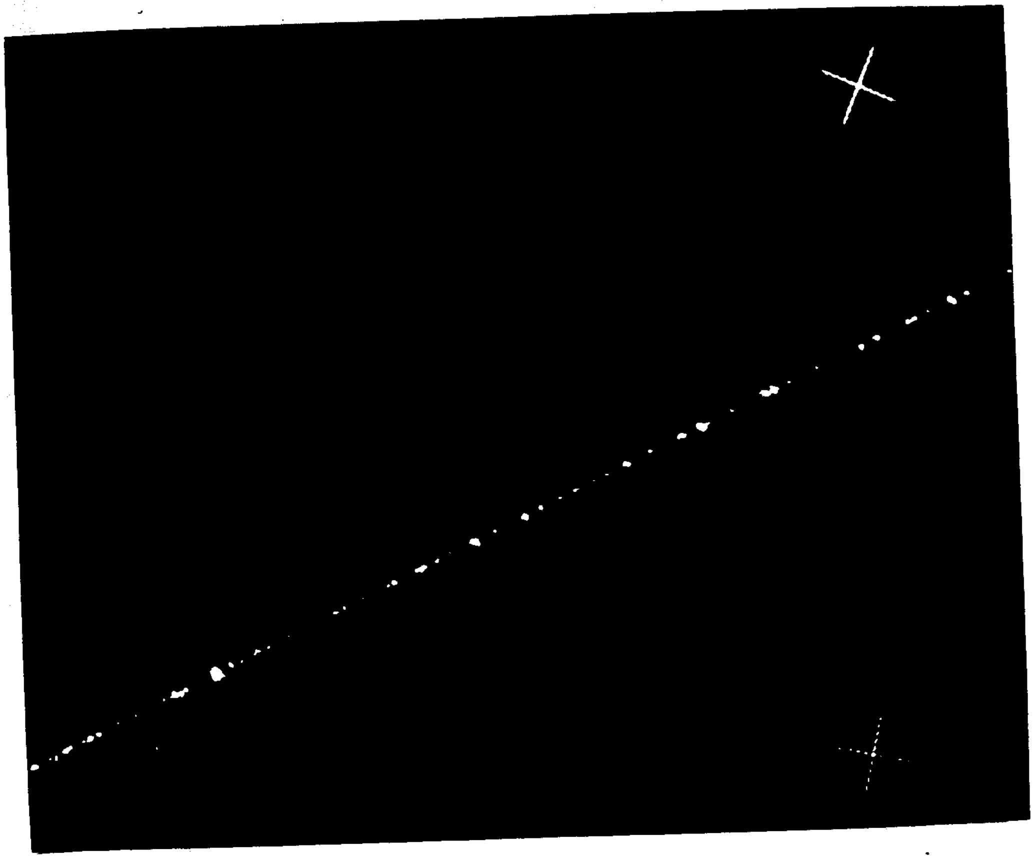
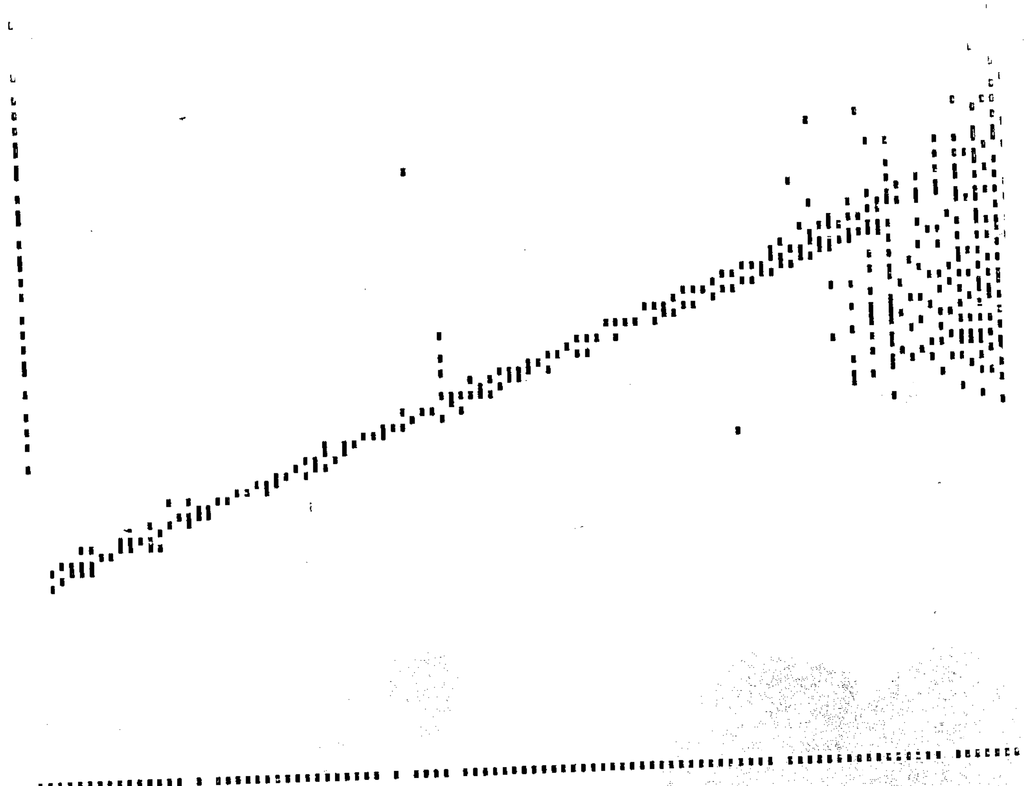

8 BITS
X SCALER
CLOCK
stop
Y
SCAL-
ER
8
BITS
CCD ARRAY
(100 × 100)
analog
output
READ X, Y
V threshold
READ
AMPLITUDE
8 BITS
A
D
C
3112A2

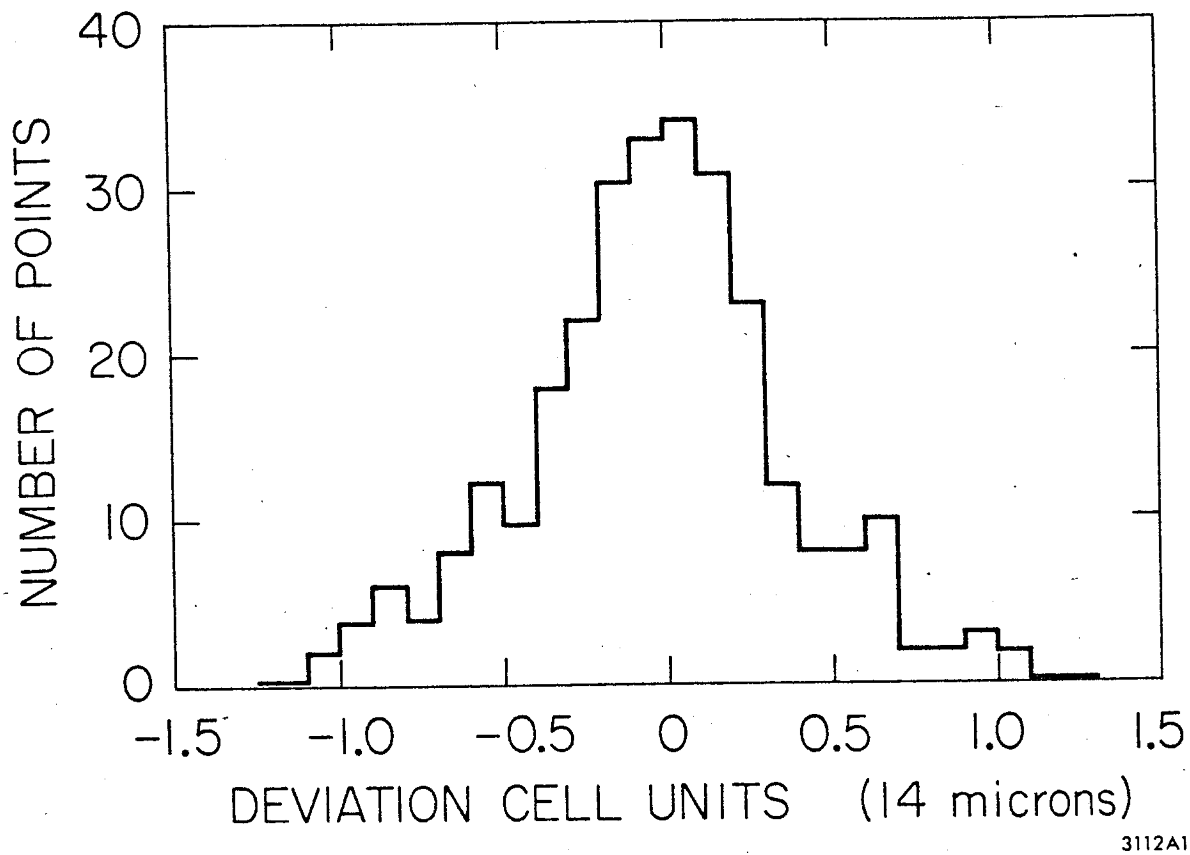
Fig. 1











40
30
20
10
0
NUMBER OF POINTS
−1.5
−1.0
−0.5
0
0.5
1.0
1.5
DEVIATION CELL UNITS (14 microns)
3112A1

Fig. 4