CHARGE DIVISION READOUT OF A TWO-DIMENSIONAL GERMANIUM STRIP DETECTOR

R.A. KROEGER[1], S.E. INDERHEES[2], W.N. JOHNSON[1], R.L. KINZER[1], J.D. KURFESS[1], N. GEHRELS[3]

[1] *Naval Research Laboratory, Washington, DC 20375-5352*
[2] *Alexandria, VA 22310*
[3] *Goddard Space Flight Center, Greenbelt, MD 20771*

Germanium strip detectors combine superior spectroscopy typical of germanium detectors with good spatial resolution. Our work has been to develop a 2-dimensional position readout of a 5 × 5 strip X-Y detector. The prototype device uses two capacitive charge division strings. Each string is read–out by two 13-bit ADCs, one on each end of the string. The four data channels are stored as an event list for subsequent processing. We form a response map over the detector surface in order to locate the position of each interaction with the spatial resolution of the strip pitch, in our case 9 mm. Cross-talk and non-linearities are removed using the response map. Energy resolution of 5.5 keV FWHM is achieved between 60 and 662 keV across the full surface of the detector.

1 Introduction

Radiation detectors that combine good energy resolution with fine spatial resolution are needed to provide spectroscopy and imaging in a single instrument. Device applications in high energy astrophysics include coded-aperture and Compton scatter telescope imaging. Superior spectroscopy is needed to resolve suspected cyclotron features [1, 2], determine annihilation radiation line–width [3, 4], and to improve sensitivity to narrow-line features from other sources such as supernovae [5]. Superior spatial resolution is needed to localize unknown sources and resolve closely spaced sources. Applications in other fields such as medical imaging are also clear. Superior energy resolution will improve Compton suppression of scattered γ-rays, thus reducing fog and ghosting in Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET) images.

Germanium strip detectors are capable of providing excellent spatial and energy resolution. Such devices are fabricated from planar germanium by cutting [6], etching [7], and photomask [8] techniques. In a two-dimensional detector, strips on opposite faces are orthogonal, as shown in Figure 1. Capacitive [9] and resistive [10] charge division networks have been used for strip readout, primarily to avoid the large number of electronics channels required.

2 Experiment

A 5 × 5 germanium strip detector was made available to us for this work, on loan from P. Durouchoux, Saclay, France. The detector was fabricated using a photomask technique by Intertechnique with 9 mm pitch by 45 mm long strips. The active volume of the detector is 45 × 45 × 12 mm, with a guard ring around the outer periphery. Electrical connections to the detector strips are made through a vacuum bulkhead. Strips on the high voltage plane are isolated by a 500 pF blocking capacitor.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1993**	2. REPORT TYPE	3. DATES COVERED **00-00-1993 to 00-00-1993**

4. TITLE AND SUBTITLE **Charge Division Readout of a Two-Dimensional Germanium Strip Detector**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,4555 Overlook Avenue, SW,Washington,DC,20375**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**5**	

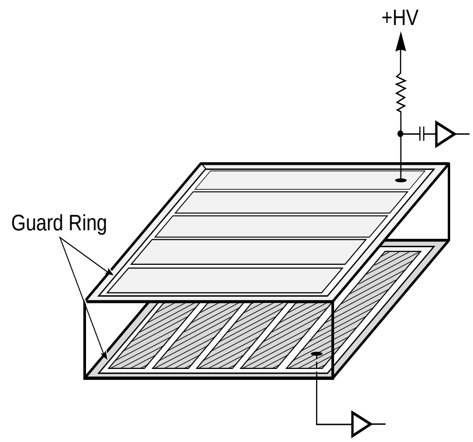

Figure 1: Schematic of the germanium strip detector used in this work. Crossed-electrodes provide two-dimensional position localization of interactions. The electrodes may be grouped in two charge-division chains, one for each side, then readout with four channels of electronics (not shown here). The guard ring provides increased immunity to leakage currents.

Capacitance to ground for individual strips is approximately 30 pF. The bulk of this is due to parasitic capacitance of cabling inside the vacuum housing and from the vacuum feed–throughs. Energy resolution on individual top and bottom strips ranges from 2.2 to 2.4 keV measured using 662 keV γ-rays and room temperature electronics.

The charge division network consists of six capacitors connected in series with strips connected to each of the intermediate nodes. Signals from each end of the network are sent through a preamplifier and shaping amplifier ($\tau_s \approx 3\mu$s). Separate networks are connected for the top and bottom sets of strips. A master gate signal is formed by discriminating on the sum signal from one of the networks. All four signals are processed in separate 13 bit ADCs read out in event–by–event list mode and stored for later processing.

3 Results and Discussion

The detector was exposed to a near-uniform illumination of both 662 keV γ-rays from ^{137}Cs and 60 keV γ-rays from ^{241}Am. Events from a charge division network using 100 pF capacitors are shown in Figure 2. These data clearly show the distinct interactions in the five strips. Events interacting in a single strip form each of the radial spokes. Photo-peak interactions appear as an enhancement at the end of each spoke. Cross-talk is observed to broaden the photo-peak along a 45 degree line in this figure with a magnitude of about 3% of the signal amplitude. Small capacitor values were selected to enhance cross-talk and non-linearity for the purpose of making this figure.

The gains of each channel in both charge division networks are independently calibrated to match photopeaks from events interacting in the central pixel. Data from the central pixel

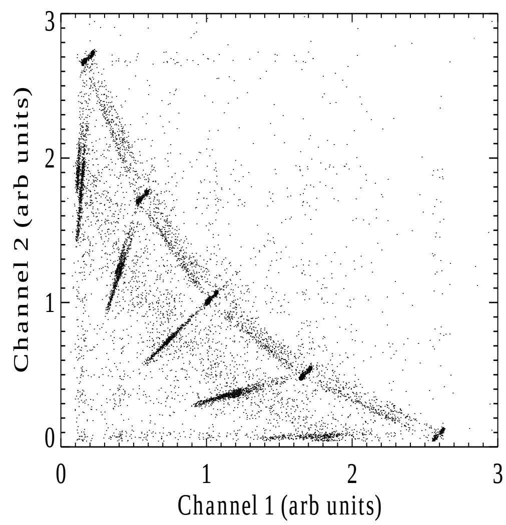

Figure 2: Scatter plot of signals from a charge division network using 100 pF capacitors. The x-axis shows the magnitude of signals on one end of the network, the y-axis on the other end. The detector was uniformly exposed to 662 keV γ-rays.

are easily identified from Figure 2 and selected for this purpose. A position coordinate for each charge division network on each side of the detector is computed using the following,

$$x = \frac{c_1 - c_2}{c_1 + c_2} \qquad \text{and,} \qquad y = \frac{c_3 - c_4}{c_3 + c_4}$$

where x and y are position coordinates ranging from -1 to 1, and c_1, c_2, are signals from the x-network, and c_3, c_4, are signals from the y-network. An image of a detector exposed to 662 keV γ-rays is shown in Figure 3. Data selected in this image are photo-peak events. Each of the 25 detector pixels are clearly distinct as sharp peaks in the image. The width of these peaks are approximately 3% Full Width Half Maximum (FWHM) of the peak–to–peak separation. Ridges between the peaks are due to events that occur within a single strip on one face of the detector, but are distributed over multiple strips on the other face.

Cross-talk between signals on both sides of the detector and non-linearity of the charge division network do not complicate the data analysis. These effects are compensated by using independent energy calibrations for each pixel. The energy scale for each pixel is well determined since cross-talk and non-linearity are constants for that pixel. Energy resolution for the array of pixels range from 5.5 keV through 5.8 keV FWHM (gaussian peak) for 662 keV γ-rays. This should be compared 2.2 keV for a single strip measured directly with a single amplifier, 4.5 keV on all 5 strips connected together, and an estimated 6.4 keV for the rms sum of two amplifiers each viewing half the signal. Energy resolution is dominated by electronic noise. The intrinsic resolution of the germanium itself is on the order of 1 keV.

Spatial resolution scales as the inverse of total energy when energy resolution is electronics noise dominated. The image from the detector exposed to 60 keV γ-rays (not shown) forms broader peaks. Individual pixels are resolved with a width of approximately 26% FWHM of the peak–to–peak separation.

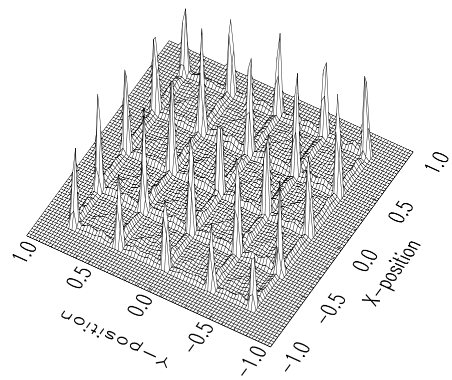

Figure 3: Image reconstruction from a uniform illumination of 662 keV γ-rays and using 500 pF capacitors charge division network. Near uniform response is achieved everywhere.

4 Conclusions

Mapping the response of a two dimensional germanium strip detector provides an effective method to remove the effects of cross-talk between the strips and non-linearity in the charge collection–particularly significant when using a charge-division network to determine event position. The data are well organized in a 2-dimensional scatter plot from which interactions in pixels (intersecting strips) are readily identified. The energy scale for each pixel must be independently calibrated. Energy resolution of the detector was limited by our electronics noise in these experiments, and not by any non-removable effects of cross-talk and non-linearity.

The detector in this experiment was used without modifications and therefore can be optimized for better performance. For example, superior performance has been previously demonstrated on a 20 strip 1-dimensional detector with a strip capacitance six times lower than in our detector [9]. Energy resolution was degraded primarily by the large parasitic capacitance on each strip. This is easily improved by packaging the charge division network inside the detector vacuum housing, although this design makes modifications difficult. Other design improvements to reduce capacitance are also possible.

References

[1] Makishima, Proc. of 28th Yamada Conf. on Frontiers of X-Ray Astronomy (1991)

[2] Kendziorra, et al., Proc. of 28th Yamada Conf. on Frontiers of X-Ray Astronomy (1991).

[3] W.N. Johnson, et al., Astrophys. J. 172 (1972), L1

[4] Leventhal, M., et al., Astrophys. J. 225 (1978), L11

[5] D.D. Clayton, Ap.J., 188, (1974), 155.

[6] P.A. Schlosser, et al., IEEE Trans. Nucl. Sci. NS-21 (1974) 658.

[7] P.N. Luke, IEEE Trans. Nucl. Sci., NS-31, No. 1 (1984) 312.

[8] D. Gutknecht, Nuc. Instr. and Meth., A228 (1990) 13.

[9] D. Bloyet, et al., IEEE Trans. Nucl. Sci., Vol 39, No. 2, (1992) 315.

[10] M.S. Gerber and D.W. Miller, Nucl Instr. and Meth., 138 (1976) 445.