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LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California

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Leon Kaufmann, UC San Francisco
David C. Camp, James H. McQuaid, LLL
Guy A. Armantrout, Steve P. Swierkowski, LLL
Kai Lee, LBL

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Leon Kaufman, University of California, San Francisco, Ca

David C. Camp, James H. McQuaid, Guy A. Armantrout and
Steve P. Swierkowski, Lawrence Livermore Laboratory, Livermore, Ca, and

Kai Lee, Lawrence Berkeley Laboratory, Berkeley, Ca

Summary

High purity germanium offers excellent potential for use in nuclear medical imaging cameras. A position and energy readout technique using two inexpensive delay lines has been developed for these cameras. Results obtained with a 1-cm^2, 4 mm deep, 5x5 strip high purity germanium detector are 2.1 mm full width spatial resolution, a measured single strip resolution of 0.65 mm full width half maximum (FWHM), a 25 element uncollimated energy resolution of 2.95 keV FWHM, and 2.65 keV FWHM for a single central element at 140 keV.

Introduction

The advantages for nuclear medicine imaging from detectors offering high spatial resolution and good energy resolution have been previously presented[1-5]. Small Germanium gamma-ray imaging cameras have also been described[6-8]. High purity germanium, used for the detector described in reference 8, is the most attractive candidate for constructing reliable large cameras of a practical clinical size. For this kind of camera, a large number of elements are needed, and the technique of using one amplifier per strip[6,8] quickly escalates the cost of the device beyond justifiable levels.

We have investigated the characteristics of an electromagnetic delay line readout technique for solid state gamma-ray cameras. The use of two inexpensive delay lines, together with a low cost display package previously developed for multi-wire proportional chamber readout[9], provide financially credible means to develop a large area high purity germanium gamma-ray camera.

Methods

Detector. The detector used in this work is made from 1 x 1 cm^2, 4 mm deep high purity germanium. Four grooves 0.6 mm wide x 0.5 mm deep were cut in each face, the grooves of one face orthogonal to those of the other. This grooved detector configuration was chosen simply to allow testing of the readout scheme. The grooves define five 1.5 mm wide strips in each face, which give a single element area of 2.25 mm^2. The 25 elements comprise a total active area of 56.25 mm^2, about 56% of the entire detector. The finite width grooves create dead areas under which little or no charge collection occurs and reduce the effective efficiency of the detector. The useful area of the detector can probably be increased by fabricating narrower grooves. Figure 1 shows a drawing of how the detector is mounted. Detector bias voltage is applied through the 3-mil platinum wires at the top. These five wires are attached to a multipin connector (not shown). Similarly, the wires from the indium-coated copper strips attach to a second multipin connector. All of the necessary position information for any of the 25 elements is obtained through these two connectors.

Readout Circuitry. Figure 2 shows a block diagram of the system used to process the events in the 25-element detector. The five strips on each face of the detector are connected to alternate sections of a lumped-constant delay line made of discrete sections of individual inductors and capacitors. The twelve section delay line has a characteristic impedance of 5 kohm and a delay of 50 ns per section. An event in any given element will produce a signal which has a delay proportional to its x,y location in the 25-element array. The ground plane of the Y delay line provides a prompt start signal for both the X and Y delay lines, as well as a suitable signal for energy discrimination. The start and two stop signals from each preamplifier are sent to zero-crossing discriminators which provide accurate timing pulses for the dual time to amplitude converter (TAC). The time intervals between start and stop for both the X and Y pulses are transformed by the TACs to pulse heights proportional to the X and Y delay time intervals. The TAC output signals drive the X and Y deflection plates of a cathode ray tube (CRT).

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The preamplifier which derives the start signal also provides energy information. Since the objective of a multi-element detector is good energy and position information, the Y delay line cannot be terminated in the conventional manner. Terminating the delay line in its characteristic impedance would give rise to a parallel noise equivalent to about 80 keV, which is clearly undesirable. Therefore, the delay line is terminated in a high pass filter, shown by Z in Figure 2. This reduces ringing and maintains a good signal-to-noise ratio.

The shaping amplifier optimizes the signal-to-noise ratio of the energy channel and provides bipolar output pulses for the single channel analyzer (SCA). The SCA allows energy selection of the events to be recorded.

The LOGIC unit utilizes the timing pulses to determine if two separate events occur within the resolving time of the delay line. In such cases, both events are rejected. This unit also checks for the presence of both X and Y signals within a preset coincidence time. The unit will also allow for display of a selected area of interest. Thus, only single events with no associated pile-up are validated by the LOGIC unit, making the intrinsic dead time of the detector equal to the travel time along the delay line. In practice, system dead time will be limited by the longer time required to display or record an event (2 to 10 μsec). Valid events, when in coincidence with appropriately selected SCA events produce an output pulse from the slow coincidence circuit which initiates intensification of the CRT beam after it has swept to an x,y position directed by the TAC. Thus, bright dots on the CRT face correspond to the detection of a gamma ray in an analogous position in the 25-element germanium detector.

The accumulation interval is controlled by a preset number of counts or seconds (scaler-timer). Photographs of the CRT screen are taken with a camera's shutter open during the accumulation interval. An appropriately programmed two-parameter analyzer or a small computer could be used to present a live display of incoming or stored x,y information.

Results

Spatial Resolution. The spatial resolution of the germanium camera was tested with 140 keV gamma rays from a Tc-99m source. Because of the way the detector has been constructed, the spatial resolution is limited to the center to center distance of 2.1 mm between strips. Results obtained under varying experimental conditions are shown in Figure 3. Figures 3A and B show the readout obtained from the Y delay line for uncollimated and collimated Tc-99m radiation. The non-uniform separations of the peaks seen in Figure 3A are not characteristic of the detector, rather they indicate variations in the values of the 20% tolerance components used to construct the delay line. The average spatial resolution of any single strip response in Figure 3A is 0.65 mm FWHM. Variations in the individual peak widths are due to the different charge collection characteristics of each strip. A more sophisticated construction technique for the germanium camera would eliminate these variations. The observed spatial resolution depends on delay line characteristics and signal-to-noise values, and it suggests that about 1 mm center to center strip distances may be the minimum feasible spatial separation in this energy range.

Figure 3C shows the two dimensional response of the germanium camera to uncollimated radiation. The Y axis separation is somewhat clearer than the X axis separations because of the improved signal-to-noise ratio for the Y delay line signals. Finally, Figure 3D shows the response of the detector to a 1 mm diameter collimated beam of Tc-99m radiation. Very little, if any, evidence of the neighboring elements is observed.

Energy Resolution. The energy resolution of the germanium camera was measured at low energies with Co-57 and Tc-99m sources. Spectra taken with these sources are shown in Figure 4. An energy resolution of 2.95 keV FWHM was obtained when the entire detector was illuminated with uncollimated radiation. This resolution corresponds to 2.1% FWHM of the 140 keV Tc-99m gamma ray. An energy resolution of 2.65 keV FWHM was observed when a single central element was illuminated with a 1 mm diater collimated beam. Table I summarizes the low energy resolution results and indicates the detector and electronic contributions of the observed values.

A Na-22 source, which has gamma rays at 511 keV and 1.27 MeV, and a Cs-137 source, which has a single gamma ray at 662 keV, were also used to observe the high energy performance of the detector. The energy resolution observed was 4.6 keV (0.7%) FWHM for the Cs-137 peak.

Imaging

Although imaging is difficult to demonstrate with this small detector, the improvement in image contrast, which results when the single channel analyzer is used to select only full energy events, can be shown. A small lead absorber in the shape of the letter "x" was made. It was placed over the multi-element detector so that the crosses of the "x" lay along the diagonals of the square detector. This allowed the four center elements along the top, bottom, and two sides to receive full illumination. The other off diagonal elements were only partially illuminated. Figure 5A shows the result of placing the "x" absorber over the detector and illuminating it with an uncollimated Co-57 point source. The shape of the absorber is not clearly defined when the SCA accepts all energies because scattered radiation deposited in any element is displayed. Figure 5B shows data taken for the exact same length of time as that in 5A; however, the SCA was set to accept only events within a 4 keV window centered at 122 keV. The image is considerably enhanced and the definition of the absorber is much more clearly observed than in 5A.

Discussion

Delay line readouts for germanium gamma ray imaging cameras offer distinct advantages over amplifier per strip readout techniques. The cost of the readout electronics is almost independent of the size of the camera and of the strip spacing. Thus, two inexpensive delay lines can handle a large number of strips.

Improved detector fabrication techniques can be used to create smaller and more closely spaced strips thereby increasing the useable area of the detector. These more closely spaced strips may increase the crosstalk between elements; however, the zero crossing discriminators used with the delay line readout technique pick the centroid of the signals from the individual strips. Thus, increased crosstalk is not a problem with this readout technique.

An extension of this work to larger area devices is feasible. The energy resolution performance of a larger (10 to 20 cm square) germanium camera is expected to be comparable to that presented here. Characteristics of the delay line readout technique are independent of detector size, thus no degradation of position resolution is expected in larger devices.

Acknowledgments

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TABLE I
PROTOTYPE GERMANIUM CAMERA ENERGY RESOLUTION

	FWHM (KEV)	
	All Elements	Single Element Collimation
Tc 99-M (140 KEV)	2.95	2.65
Pulser	2.40	
Detector Contribution	1.72	1.12
Theoretical Detector Contribution F=0.1	0.47	

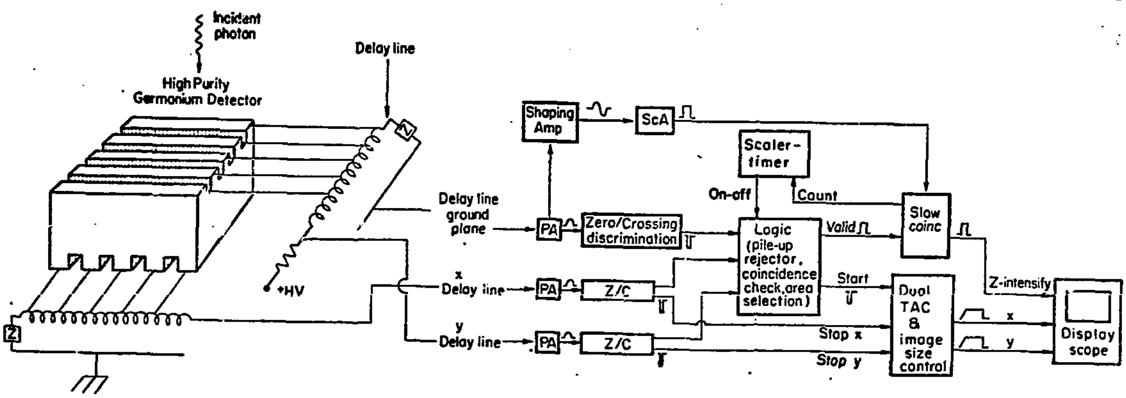

Figure 2

Figure Captions

Figure 1. Drawing of the germanium detector and mounting. The detector construction shown here was chosen simply to test the delay line readout scheme.

Figure 2. Schematic diagram of the delay line readout technique used for the germanium camera.

Figure 3. The spatial resolution of the germanium camera was defined with a Tc-99m radiation source (140 keV gamma ray). The 1 cm scale applies to the four photographs.

A. The camera's spatial response along the Y axis is shown by the five peaks. The average single strip spatial resolution is 0.65 mm FWHM. The unequal peak separations are due to variations in delay line component values.

B. Cross-sectional response along the Y axis with the source collimated to illuminate one image element.

C. Two-dimensional image of the 25-element detector, defined by uncollimated radiation.

D. The source was collimated to 1 mm and illuminated only one of the twenty-five image elements.

Figure 4. Energy spectra obtained with the germanium camera and several radiation sources.

A. Uncollimated Co-57 illuminated the entire detector. The major peak is the 122 keV gamma ray, the smaller peak to the right is the 136 keV line. The small peaks to the left are lead x-rays produced by fluorescence of lead shielding. The energy resolution is 2.95 keV FWHM.

B. Tc-99m 140 keV, was used to illuminate the entire detector. The energy resolution is 2.1% FWHM. Again the lead x-rays can be seen to the left of the main peak.

C. Tc-99m was collimated to illuminate a single crystal element in the camera. The energy resolution has improved to 1.9%, or 2.65 keV, FWHM.

D. Spectrum obtained with Co-57 and Tc-99m illuminating the entire detector. The source intensities were adjusted to obtain approximately equal count-rates for the 136 keV and 140 keV peaks, seen to the right.

E. An expanded display of the 136 and 140 keV lines demonstrates the germanium camera.

Figure 5. Images of a lead absorber, in the shape of a cross with 3 mm wide arms, using a Co-57 point source.

A. The single channel analyzer was set to accept both full energy and scattered radiations from the source.

B. The single channel analyzer was set to accept a 4 keV window centered on the primary 122 keV radiation of Co-57.

C. The lead cross shown to scale.

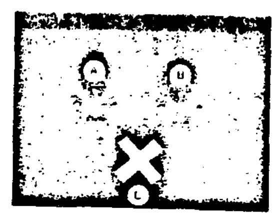

Figure 5

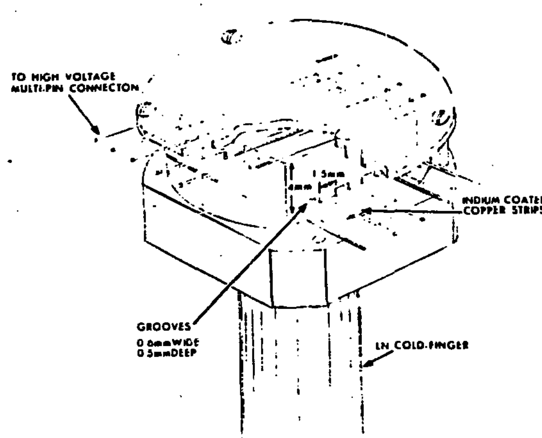

Figure 1

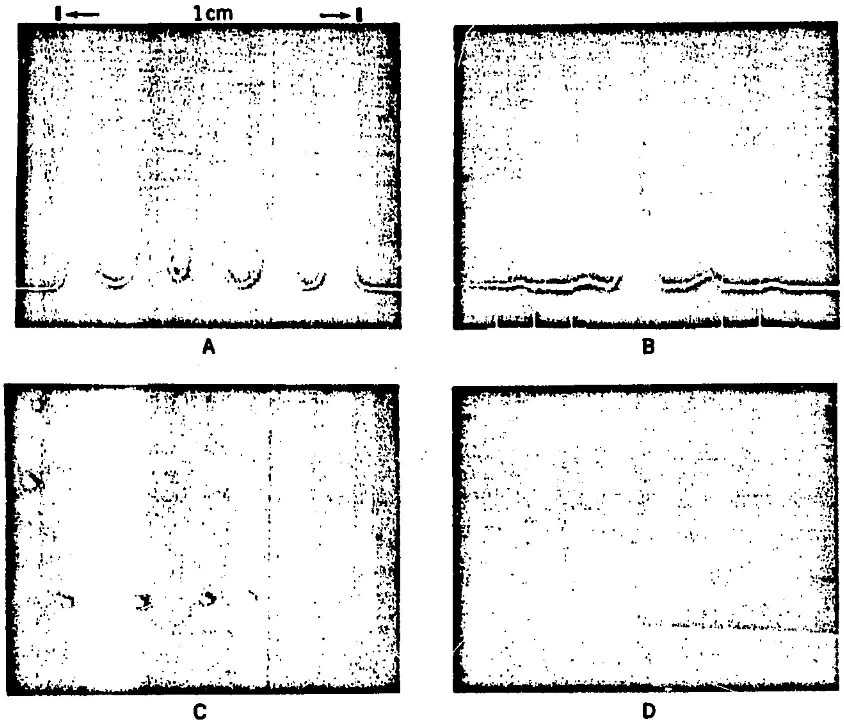

Figure 3

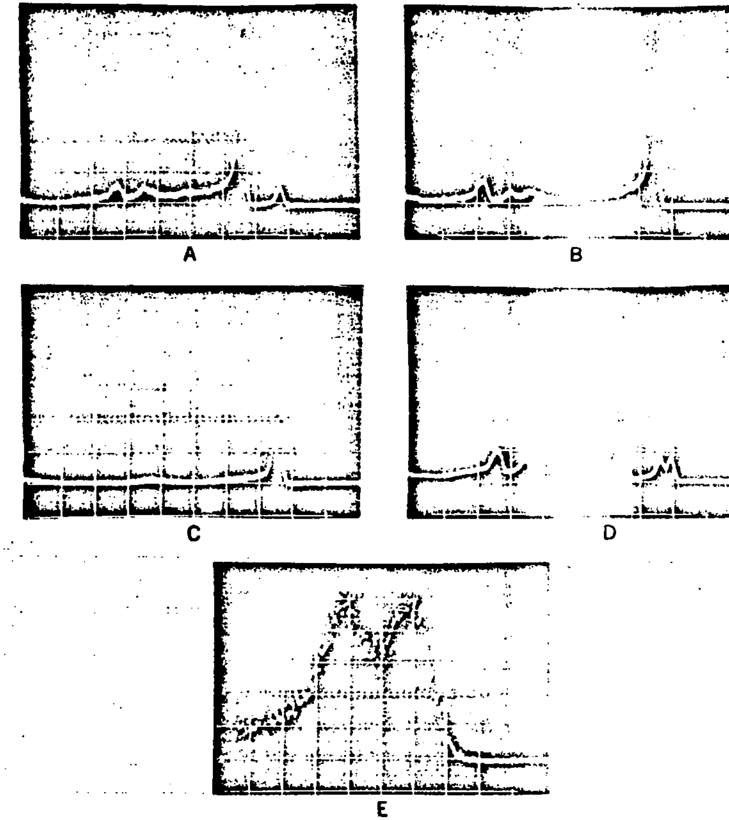

Figure 4