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Design and performance of a large area neutron sensitive anger camera

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ABSTRACT

We describe the design and performance of a 157 mm × 157 mm two dimensional neutron detector. The detector uses the Anger principle to determine the position of neutrons. We have verified FWHM resolution of <1.2 mm with distortion <0.5 mm on over 50 installed Anger Cameras. The performance of the detector is limited by the light yield of the scintillator, and it is estimated that the resolution of the current detector could be doubled with a brighter scintillator. Data collected from small ($<1\ mm^3$) single crystal reference samples at the single crystal instrument TOPAZ provide results with low values of the refinement parameter $R_w(F)$.

1. Introduction

The Anger Camera first developed for the detection of gamma rays [1] analyzes the light distribution pattern from a scintillating material to determine the position of particle capture in the scintillator. This basic principle was extended for use in the detection of neutrons by using a neutron sensitive glass scintillator [2].

Like the first neutron Anger Camera, the neutron detector described in this paper uses enriched Li^6 glass as the scintillator. Improvements to the optics package and electronics of an earlier prototype of the detector [3] were made including the removal of an optical lens which introduced distortions into Bragg peaks and lowered the overall efficiency of the detector. The current design has FWHM resolutions that are reliably near 1.0 mm. A least squares fitting method, similar to one described elsewhere [4], is used to determine the position of neutron capture in the scintillator, while new routines for gamma rejection and flat field corrections have been developed which improve gamma background rejection and the positional accuracy of the detector.

2. Design

The neutron Anger Camera has three major sub-assemblies: the optical front end, the preamp and summer stack assembly and the digital processing board assembly. The complete unit along with the major subsystems is shown in Fig. 1 and is described in more detail in the paragraphs below.

2.1. Optical front end

The scintillator used in the Anger Camera detector is GS20 lithium glass from AST. The scintillator is selected at either 1.5 mm or 2.0 mm thick and is optically coupled to a 3.5 mm glass spacer that is optically coupled to an array of nine 64 element photomultiplier tubes (PMTs). The thicker scintillators are used in installations where enhanced neutron detection efficiency at low neutron wavelength is required. The scintillator extends slightly beyond the physical edge of the PMTs and provides an active area of 157 mm by 157 mm. Fig. 2 shows a cross-section of this assembly. To improve the light collection, the top of the scintillator is painted with a white diffuse reflecting paint (Saint-Gobain BC620). The primary purpose of the glass spacer is to allow expansion of the light cone to span the tube gaps. As described in other designs, gaps between optically active elements have a major impact on the performance of the detector [5,6]. All glass interfaces are coupled using silicone gel. Because of the slight curvature of the glass window of the PMT a compliant gel "cookie" is also used at the glass spacer PMT interface. In general we find that the resolution is improved with decreasing spacer thickness. Tests with a higher light yield scintillator indicate the current configuration's position resolution is light yield limited. (See Appendix A)

2.2. Single PMT processing electronics

Fig. 3 shows the different electronic subsystems and how they are interconnected for a single photomultiplier tube. There are nine of these sections in a complete Anger Camera detector. For each phototube the original 64 pixels are transformed into 8 horizontal (x) and 8 vertical (y) values. The preamplifier, summer stack and A/D Conversion Electronic subsystems are described below.

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Fig. 1. Showing a complete Anger Camera Assembly. The "snout" on the right contains the optics package and preamp electronics. The signal processing boards are also visible within the body of the detector.

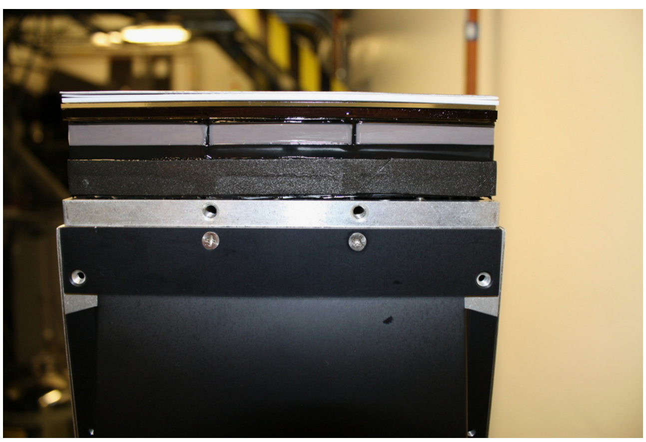

Fig. 2. Shows a cross-section of the Optics Package. Starting at the top of the optics package we have a white reflector with the scintillator just below (also white in appearance). Just below the scintillator is a glass spacer (dark in color) which is optically coupled to the phototubes that are the three gray units just below the glass spacer. Note the gaps between phototubes. These optically inactive gaps are about 4 mm wide and not only reduce the number of photons collected from a scintillation event, they cause errors in the position calculation which must be corrected.

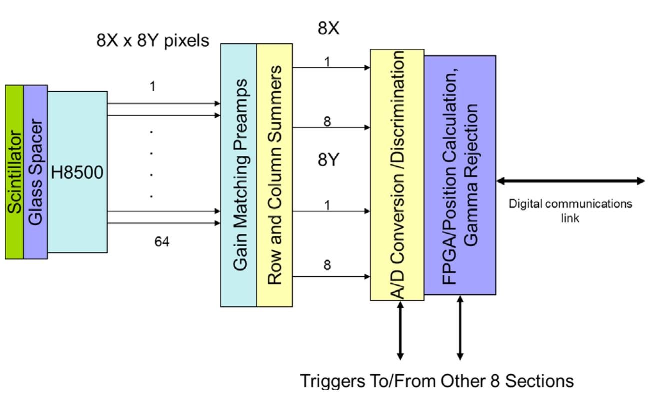

Fig. 3. Showing the signal flow of the Anger camera. The diagram represents one of nine conversion components denoted as AROC boards in the text. Trigger signals are used to synchronize data collection across the nine conversion electronic (AROC) boards.

2.2.1. Preamplifier electronics

The preamplifier stage consists of 64 trans-impedance amplifiers. The trans-impedance feedback resistors are specifically chosen to compensate for the differences in the gains of the different phototube elements. The variation in gains of the 64 phototube elements can be as large as $\pm 50\%$ with a typical variation being $\pm 20\%$. The appropriate values of the feedback resistors are determined from data provided by the manufacturer.

2.2.2. Summing stages

The elements in each row and column of each tube are summed together using summing amplifiers. The outputs of the summing amplifiers are input into a gated integration stage and also to the discriminator electronics. The output of the integrator provides 16 signals (8 X and 8 Y) to the A/D convertor. By summing individual elements to create rows and columns the electronics is simplified considerably.

2.2.3. Conversion stage

Each of the row and column signals is delayed via a 200 ns delay line and feed into a 10 bit pipeline A/D convertor. The time delay allows integration of the incoming signal to begin just before the rising edge of the signal. Each row and column signal is also feed into a simple threshold discriminator circuit (with hysteresis). The output of the discriminator and the A/D convertor are feed into a Spartan 3 FPGA. The conversion electronics, discriminator electronics as well as digital communication and timing links comprise what is known as an Anger camera Read Out Control (AROC) board. Each Anger camera uses nine of these boards, one for each PMT. Trigger signals to and from each of the nine boards are used to synchronize the integration timing and data collection over the entire detector array.

2.3. Digital processing board

The nine AROC boards send digital conversion data to the Anger Camera Position Calculation (ACPC) board. The ACPC virtualizes the nine AROC boards so that the system appears as one detector unit rather than nine. After receipt of conversion data from all nine AROC boards, the ACPC then calculates the position of the detected neutron. The ACPC board is also responsible for external digital communications, as well as forwarding configuration and control data to and from the AROC boards. We describe the data flow from the AROC boards to the ACPC as well as the position calculation method in the following paragraphs.

2.3.1. Data flow

Whenever a row or column signal exceeds the hardware discriminator threshold in an AROC board, the AROC FPGA logic sets a global trigger signal high. The other eight AROC boards use this signal to initiate data collection timing. After a specified programmable delay (typically 2 ticks, where 1 tick = 50 ns) from the trigger signal, the integrator gate of all nine AROCs are released starting the hardware integration process. After m ticks (m is programmable), where m is typically 12, the output of the integrator is captured. Thus, whenever any of the 144 (8 row plus 8 column signals for each of 9 phototubes) signals trigger the hardware, 144 A/D conversion values along with a timestamp are captured by the FPGA logic. Each AROC board communicates the 16 A/D conversion values it collects to the ACPC board.

The $9*16 = 144$ values are used by the ACPC to calculate the neutron position. The first step in the calculation is to remove the electrical offset, and to rescale the values to eliminate variations in channel gain. The standard deviation of the channel gain is found to be of the order of 4% and is due primarily to tolerance stack up in the electrical components. These corrected 144 values are further reduced to 48 ($24x$ and $24y$) values by summing the same row (y) values and the same column (x) values for each of the