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Proof of Principle for Electronic Collimation of a Gamma Ray Detector

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PURPOSE: This note describes the initial development of an electronic collimation technique that uses the characteristics of the detector waveforms to infer the directionality of gamma rays. This note documents some of the key points in achieving the proof of principle of the technique, which is intended to be further developed. A gamma ray detector system utilizing electronic collimation should be far more portable and/or deployable than previous systems using conventional collimation with heavy shielding materials.

This research was performed to satisfy a component technology requirement for the Environmental Toolkit for Expeditionary Operations. In order to detect, discriminate, and locate radiation sources in the environment, the sensor was required to be lightweight, cheap, and operate on a small self-contained power source. Furthermore, the sensor was required to be able to communicate across a mesh-network of similar radiation sensors to send critical data back to an environmental data platform. During development of the sensor system, it became clear that proving the viability of electronic collimation would meet the sensor requirements by:

(1) reducing the weight of the sensor by removing a physical collimator, (2) provide directionality of radiation sources for stationary sensors as well as moving sensors, and (3) enable the use of lower cost and more efficient radiation sensors suitable for high energy spectroscopy in the field. Work described here demonstrates the feasibility of electronic collimation in this context and provides an epistemological foundation for completing the final sensor platform.

BACKGROUND: Any time directionality is important, some form of collimation is required. Gamma rays, the highest energy electromagnetic waves and the most penetrating form of radiation, tend to interact with charged particles (notably the electrons) volumetrically in material. Therefore, the larger the detector, the more likely it will detect any given gamma ray; hence, smaller detectors are more inefficient at detection (Knoll, 2010). The same thickness of shielding is needed for smaller detectors as for larger detectors; so, the smaller the detector, the more increasingly unsuitable using shielding alone for collimation purposes is.

A numerical example helps to illustrate the use of shielding alone. Using strictly shielding for collimation requires sufficient material to block out gamma rays coming from all directions except the desired one. Heavy metals, such as lead, with many charged particles in a given volume, make the best shielding materials; however, it takes a 6.1 cm thickness of lead to block 95 percent of the 2.615 MeV gammas of the thorium series, among the most common of the high-energy gammas in the environment (Furey et al., 2009; Mane et al., 2014). To block out 95 percent of such gamma rays from entering through the sides of a cylindrical detector, for example, that same 6.1 cm thickness of lead would be required whether the detector is 30 cm in diameter or 3 cm.

Simply designing the detector to be much more inefficient in directions other than the desired direction will provide collimation of detection for other less penetrating forms of radiation, including alphas and betas, as well as X-rays (Streil et al., 2010; Bushberg et al., 2012). However, for gamma rays, a small detector, such as an ionization detector, that is extremely inefficient in most directions is therefore also inefficient in all directions. An alternative to inefficient detection is electronic collimation, in this case, using data analysis to filter a sensor's detected events by direction if there are exploitable differences between detections of gamma rays from different directions. Work in electronic collimation in recent decades has primarily focused on multi-sensor coincidence techniques, mostly in the context of high flux medical tomography, especially for so-called Compton cameras (Dogan et al., 1992; Tümer et al., 1997). Such techniques, often requiring large arrays of sensors, are not suitable for lower level environmental applications, especially when directionality and/or spectroscopy may be needed from one sensor.

Particularly, for spectroscopic purposes, the fact that many detectors have a directional waveform response has been traditionally considered as an inconvenience at best. The detector-produced waveforms traditionally have been highly preprocessed, especially analog electronics such as shaping amplifiers, to make all the waveforms look as similar as possible prior to analysis (U.S. NIM Committee, 1990). A great deal of detector research has focused on increasing the internal complexity of spectroscopic detectors, such as multi-wire, curved grids for gas proportional counters, in order to compensate the shapes of waveforms for directional effects (Fujieda and Perez-Mendez, 1987; Silva et al., 1999).

In the course of analyzing the potential for small deployable detector systems for gamma rays in the environment, researchers realized that even the minimal amount of collimator shielding was too much for portability reasons (Furey and Morgan, 2011). Instead of abandoning the possibility of collimation for small detectors, researchers decided to investigate other methods of collimation. For cylindrical detectors, electronically discriminating transverse (across the cylinder axis) waveforms from longitudinal (along the axis) waveforms yield proof of principle.

TECHNOLOGY DESCRIPTION: The component detector technologies were mounted in custom polyethylene holders, and attached to NIM modules with short (< 1 m) RG174 coaxial cables using BNC connectors (Figure 1). An Ortec model 456 power supply was used to operate an inexpensive Geiger tube (type SBM-19/STS6, purchased from The Electronic Goldmine, Scottsdale, AZ) in its very limited proportionality mode at 283.2 V, with sealed gamma sources (1 μCi each of Ba-133, Cs-137, and Co-60, purchased from The Nucleus Inc., Oak Ridge, TN), inside a copper quartic collimator borehole sighted onto the Geiger tube (Figure 2). The distance from the stacked source disks to the Geiger tube was approximately 25 cm.

Electronic design for waveforms centered on an Amptek A250 circuit to deliver waveforms digitized with an Agilent U2353A at 500 kHz (Figure 3). For this proof of principle, the 16-bit waveforms were streamed to a PC hard drive and analyzed with custom Visual Basic (VB6) code after acquisition. During acquisition, the signals were split to a Tektronix TDS 3032 digital oscilloscope for visual monitoring.

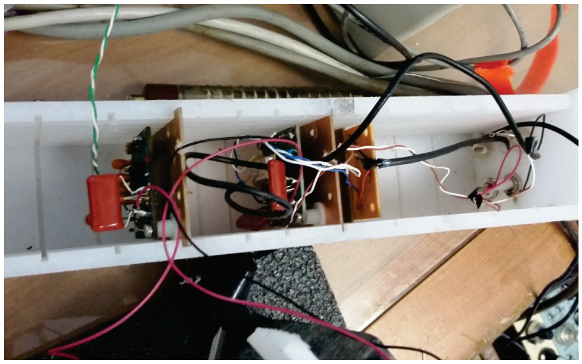

Figure 1. This photograph illustrates the electronic configuration for the laboratory experiments sitting on interchangeable boards that are housed in a custom polyethylene box. The high voltage and signal cable pass-throughs are seen at right.

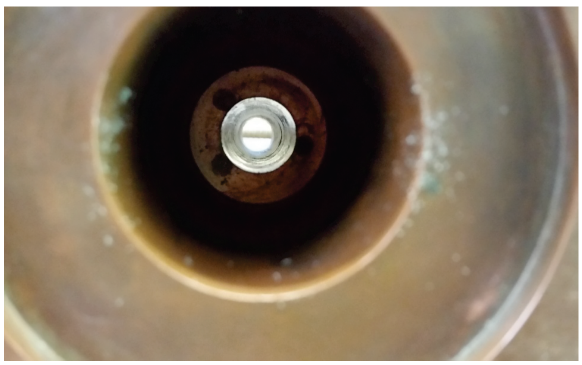

Figure 2. This photograph illustrates the borehole sighting through the copper collimator, with source disks (and wadding) removed. The transverse Geiger tube is evident in the center of the collimator opening.

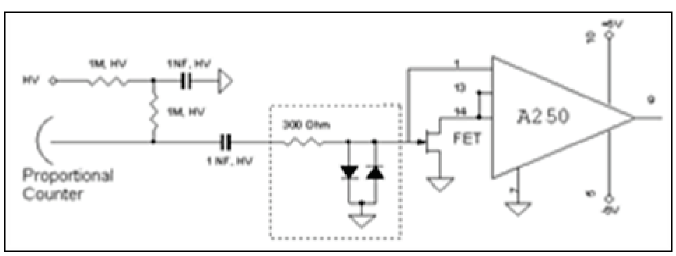

Figure 3. This drawing illustrates the electronic design.

Several hours of acquisitions under various conditions yielded thousands of detected events; but for directionality considerations, the two main configurations for comparison were transverse and longitudinal (Figure 4). A typical waveform for the transverse configuration is shown in Figure 5, with a 335 mV offset under these acquisition conditions. The waveform widths, defined as full width at half maximum (FWHM), for positive portions (of approximately eight thousand transverse and longitudinal waveforms) are significantly different at the 99 percent confidence level (p-value $< 10^{-5}$) as illustrated in Figure 6.

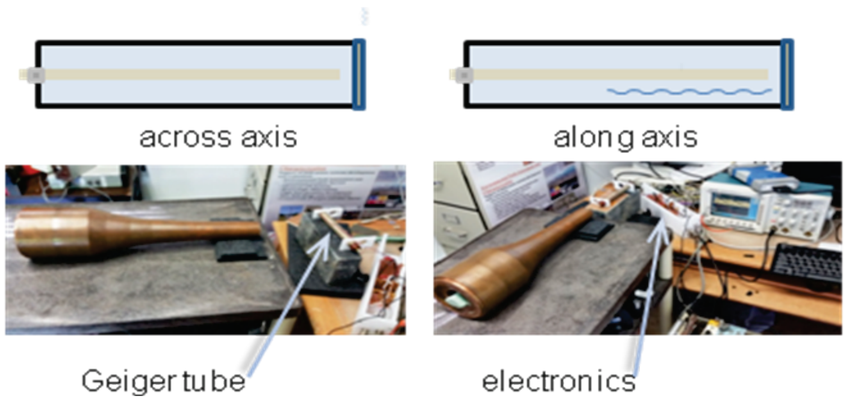

Figure 4. These photos illustrate the geometry of acquisition. Transverse waveforms were acquired with gamma rays entering across the axis (left), and longitudinal waveforms were acquired with gamma rays entering along the axis (right).

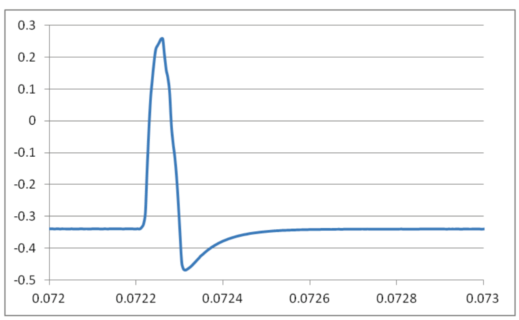

Figure 5. Illustrates a typical waveform, as acquired in raw time series form.

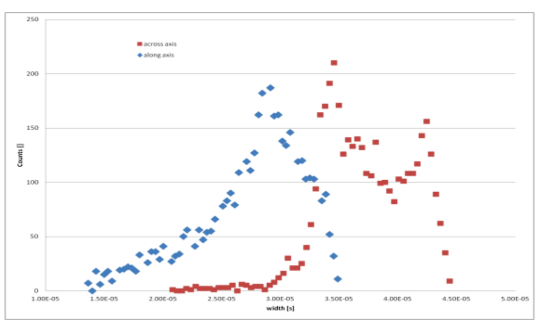

Figure 6. Histograms of widths (positive FWHM) of analyzed waveforms, showing a clear difference between transverse and longitudinal detections.

Although other waveform parameters could improve the discrimination beyond this scalar quadruople (l=2, m=0) directionality, this simple difference by itself confirms the proof of principle. Other time-domain shape parameters, such as slopes, could also be used to more closely estimate cylindrically-symmetric inclination angles by using mixture analyses to impart finer directionality for these waveforms. The waveform directionality from several oriented detectors can be further combined to infer true vector directions, for example, for locating hot spots in a low-level background.

EXAMPLE APPLICATIONS: The immediate applications for electronic collimation of a gamma ray spectroscopic detector will include identifying and characterizing environmentally hazardous radioactivity to complete the Environmental Baseline Survey mission for soldiers. The monitoring of radioactive waste handling, as well as other sources of radioactive contamination in the environment, can also benefit from reduced cost sensor platforms.

CONCLUSIONS AND RECOMMENDATIONS: This effort demonstrates, with experimental rigor, that electronic collimation is possible by discriminating the waveforms produced from longitudinal and transverse gamma ray strike geometries. It is expected that the aforementioned sensing circuit design can be reduced to an easily portable (< 0.5 kg) detector with a small form-factor (< 800 cm^3), even when including a slightly larger gas-proportional tube to improve the signal to noise ratio, and electronics sufficient to operate and establish a mesh network. Such a system does provide the potential for greater technological dominance in gamma ray sensing and detection, achieving operational goals for low cost systems (in terms of power, weight, and real dollars) that are still highly performing and portable.

Chip design can further shrink volume and power needs. On-chip, real-time waveform parameterization will greatly decrease data storage and transmission requirements, and aide the robustness of spectroscopy for low count situations. The small size and low weight will also make these kinds of sensors ideal for tracking aqueous radiological contamination in the flows of bodies of water.

ADDITIONAL INFORMATION: This technical note was prepared by John Furey, Research Physical Scientist, Cliff Morgan, Research Physicist, and Austin Davis, Research Geographer, all of the U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC) Environmental Laboratory (EL). The technology was developed as an activity of the Environmental Quality and Installations research program. This technical note should be cited as follows:

> Furey, J., C. Morgan., and A.V. Davis. 2016. *Proof of Principle for Electronic Collimation of a Gamma Ray Detector*. EQT Technical Notes. ERDC TN-EQT-16-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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