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# Zero Deadtime Spectroscopy without Full Charge Collection

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# ZERO DEADTIME SPECTROSCOPY WITHOUT FULL CHARGE COLLECTION

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**Abstract**

The Savannah River Technology Center has built a remote gamma monitoring instrument which employs data sampling techniques rather than full charge collection to perform energy spectroscopy without instrument dead time. The raw, unamplified anode output of a phototmultiplier tube is directly coupled to the instrument to generate many digital samples during the charge collection process, so that all pulse processing is done in the digital domain. The primary components are a free-running, 32 MSPS, 10-bit A/D, a field programmable gate array, FIFO buffers, and a digital signal processor (DSP). Algorithms for pulse integration, pile-up rejection, and other shape based criteria are being developed in DSP code for migration into the gate array. Spectra taken with a two inch Na(I) detector have been obtained at rates as high as 59,000 counts per second without dead time with peak resolution at 662 KeV measuring 7.3%.

## 1. Introduction

Numerous efforts have been made to enhance radiation spectroscopy through the application of digital signal processing technology. Most have fallen within two broad categories: pulse shaping to enhance resolution with a standard ADC [1, 2]; or energy determination using digital samples and suitable algorithms instead of a conventional ADC [3, 4, 5, 6]. In the majority of these approaches, preamplifier outputs are digitized for further processing. In ref. [7] a different technique directly digitized the raw anode output of a Na(I)/PMT detector with a digital oscilloscope to extract piled up pulses off-line. This technique abandoned full charge collection, relying instead on digital sampling to accurately determine pulse energy. The zero dead time instrument described here also relies on multiple samples of each detector pulse to perform energy spectroscopy.

## 2. Origin of Sampled Data Spectroscopy at SRS

In 1990 Savannah River needed a high count rate system for reactor fuel manufacturing. Because commercial systems specified 95% dead time at 200,000 counts per second, the concept of using digital sampling to build a zero dead time instrument was considered. Scouting work with a digital oscilloscope in 1992 [8] led to the following conclusions:

1. HPGe detectors would require at least 100 to 200 MSPS at more than 8 bits resolution because of their short charge collection times, irregular pulse shapes, and inherently high resolution;
2. Solid scintillator detectors (such as Na(I)/PMT's) could be adequately digitized with an 8-bit digitizer operating at 30 MSPS, although 10 bits would provide greater dynamic range.

Although an HPGe system was desirable, Na(I) was preferable for other field applications, and development could proceed using less expensive electronic components. Once the architecture and algorithms were defined, an HPGe system could be developed with fewer risks and at lower cost.

### 3.0 Architecture Description

A sampled data instrument digitizes the charge collection process (the rise time portion of a conventional tail pulse) and numerically integrates its samples to produce an energy value immediately at the end of that process. In the case of photomultipliers, this is accomplished by removing the normal charge integrating preamplifier and connecting the anode output to a free-running flash ADC with only a minimum of amplification. The large number of digital samples taken permits all pulse processing functions to be carried out in the digital domain. Besides significantly reducing the amount of analog circuitry required, this approach also reduces the number of functions that must be implemented in the digital circuitry. For example, baseline restoration and pulse shaping are no longer necessary. The FLIMFLAM1 prototype instrument described here is an evolutionary step toward true zero dead time operation. Some pulse processing functions are implemented by a digital signal processor (DSP) rather than in real time digital circuitry for flexibility during algorithm development.

The primary goals of the prototype design were as follows: to move as many functions as possible from the analog to the digital domain; to achieve equivalent energy resolution to existing analog systems; and to use the DSP to develop algorithms for migration into a gate array to achieve true zero dead time operation. The analog section (Figure 1) begins with the detector input which is low-pass filtered for anti-aliasing and terminated into 50 ohms. This low impedance input ensures low noise and high signal integrity with the long detector cables typical of remote applications. A Canberra 2007 PMT base is used, requiring only high voltage and coaxial signal return cables. The filtered detector signal is amplified by one half of a dual variable gain amplifier (VGA) with a voltage gain range of 1 to 100 and a constant bandwidth of 40 MHz. The second amplifier stage provides an inverting gain of two and an adjustable offset voltage to match the ADC's input range of approximately 2.8 to 3.8 volts. 12-bit DAC's control both the VGA gain and the ADC input offset. The other half of the VGA is used for initial and runtime calibration of the electronics, as well as for fault isolation. The free-running ADC is a 10-bit converter operating at 32 MSPS, containing both a track-and-hold amplifier and an internal voltage reference.

[insert figure 1 here]

The digital section (Figure 2) contains a gate array, two dual FIFO's, and the DSP. The continuous data stream from the ADC is fed into a Quicklogic field programmable gate array which performs simultaneous word and group discrimination to extract real pulses. Low and high word threshold tests are performed on every sample, while the number of contiguous samples that pass the word tests is counted for group testing. Individual samples must fall between the low and high word thresholds. When a sample exceeds the low word threshold, a group count is started and valid samples are written into a FIFO buffer. The group count ends when a sample falls below the low word threshold. If the group count at that point is between the minimum and maximum group thresholds, the FIFO contents are declared valid and retained for transfer to the DSP. If a sample falls below the low word threshold before the minimum group threshold is reached, a "no pulse" is declared and the FIFO contents are overwritten. Additional gate array functions include missed pulse and overranged pulse counters, FIFO read/write control, DMA transfers to the DSP, and interfaces to a quad DAC, a UART, and an S100 compatible output port. The current 7000 gate array is approximately 70% utilized.

[insert figure 2 here]

Each FIFO contains two 256 X 9 buffers for a total of four pulse buffers. Under gate array control, digitized pulses are transferred into internal DSP memory through a DMA port while the processor continues to execute its code. The DSP has sufficient data memory space for at least 48 pulse buffers. For gamma spectroscopy with solid crystal scintillators, these buffers can be limited to 64 samples each; they can be reconfigured for up to 256 samples for other applications to match the charge collection time of the detector. The DSP processes the pulse samples, performing numerical integration using a straightforward trapezoidal algorithm and can also check for evidence of pulse pile-up. Other DSP functions include spectrum collection and communication with a remote PC over a high speed RS232 link. At the PC end, Visual Basic has been used to implement standard MCA spectrum manipulation functions, as well as oscilloscope-like functions for setting the digital discriminator parameters, system gain, high voltage, etc.

## 4.0 Performance

The performance of the FLIMFLAM1 has been tested using a Canberra 802-3 two inch Na(I)/PMT detector with a Canberra 2007 tube base. Because the anode signal is terminated into 50 ohms at the FLIMFLAM1 input, the high voltage is normally in the range of 950 to 1000 volts. For comparison purposes, an Accuspec MCA was used with the same detector, a Canberra 2007P preamplifier base, and a high voltage setting of 800 volts. Spectra were taken using the same source/detector configurations for three cases (137Cs alone, 60Co alone, and both sources together) and analyzed using S100 MCA software. (Figure 3) compares spectral performance for 137Cs. FWHM calculations were 7.8% for the Accuspec and 8.0% for the FLIMFLAM1 at 662 keV, for a discernible broadening using the sampling technique. Using more favorable gain settings, FWHM's measured 7.0% and 7.3%, respectively. The effects of quantization and the integration algorithm are more noticeable below 100 keV, where the number of samples taken per pulse is smaller and the trapezoidal approximation to the true integral is less accurate. The spectra for both sources in (Figure 4) show more evidence of peak broadening in the valley between the 60Co peaks. Since the pulse pile-up rejection algorithm was not operating during these collections, the summing range extending beyond the Cobalt peaks appears the same in both spectra.

[insert figures 3 and 4 here]

Each of the spectra shown were collected in 60 seconds. (Table 1) compares the counting and dead time performance between the Accuspec and FLIMFLAM1 systems. An attempt was made to measure the dead time performance of the FLIMFLAM1 using the traditional two source method [9]. This resulted in a gross calculated dead time of 12.3% with no pile-up correction. A problem arose when attempting to apply the conventional correction algorithm [10], since there is not a fixed pulse length with which to calculate the percentage of pile-up which should be observed. Two forms of dead time monitoring are used within the instrument itself which indicated pile-up losses of less than ten counts per million in further testing at 59,000 counts per second.

[insert table 1 here]

**5.0 Development directions**

Algorithm developments will concentrate on improving energy resolution, spectral linearity, and pile-up rejection, while hardware development will focus on lower power consumption and higher digitizing rates. FLIMFLAM1 consumes about five watts, including the high voltage supply. For remote and handheld applications, an iteration is planned for 3.3 VDC digital circuits operating at 40 MHz and +/- 5VDC analog circuits, reducing power consumption to approximately three watts. For stationary applications sampling rates will be further increased to improve linearity at low pulse energy levels. Interfaces to HPGe and other solid state detectors are also being investigated. To achieve the benefits of zero dead time operation, a transistor reset preamplifier appears to be essential along with a suitable algorithm for processing either integrated pulses or fast timing outputs. Current plans include applying CdZnTe detectors in remote applications.

**6.0 Summary**

The architecture of a sampled data instrument has been presented in its current prototype form. Its performance versus conventional instruments using a Na(I)/PMT detector indicates that it achieves practical zero dead time operation without significantly compromising the resolution of the detector. By not employing full charge collection, it simplifies the electronics required to implement an energy spectroscopy instrument.

**7.0 Acknowledgments**

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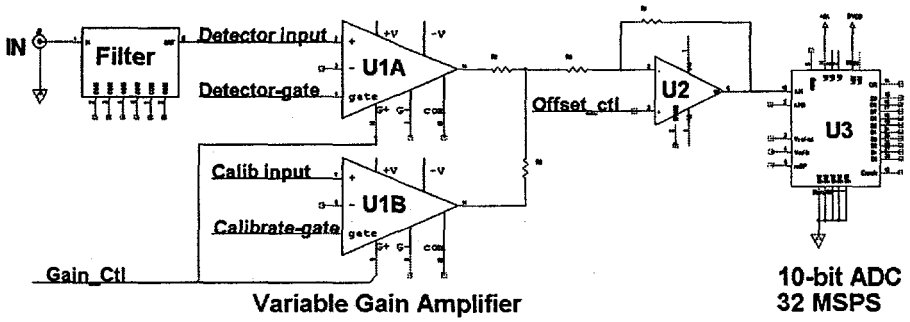


Figure 1. Analog circuitry, FLIMFLAM1, from detector input through flash ADC.

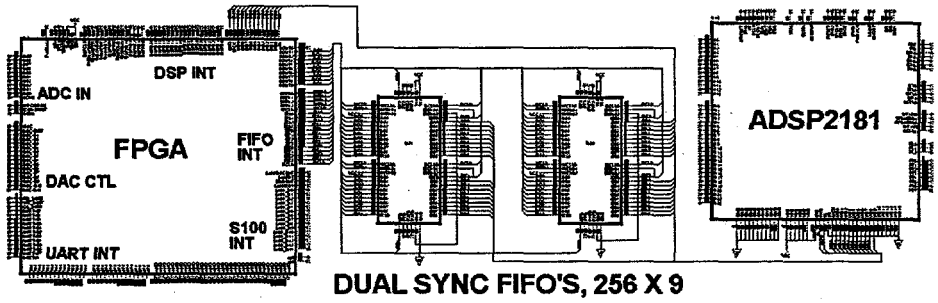


Figure 2. Digital circuitry, FLIMFLAM1, from flash ADC output through DSP.

FLIMFLAM1, 137Cs, 60 sec. Accuspec, 137Cs, 60 sec.

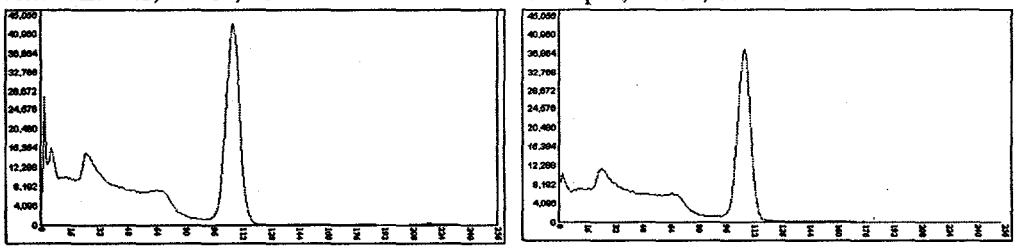

Figure 3. Peak comparison at 662 keV between FLIMFLAM1 and Accuspec.

FLIMFLAM1, 137Cs + 60Co, 60 sec. Accuspec, 137Cs + 60Co, 60 sec.

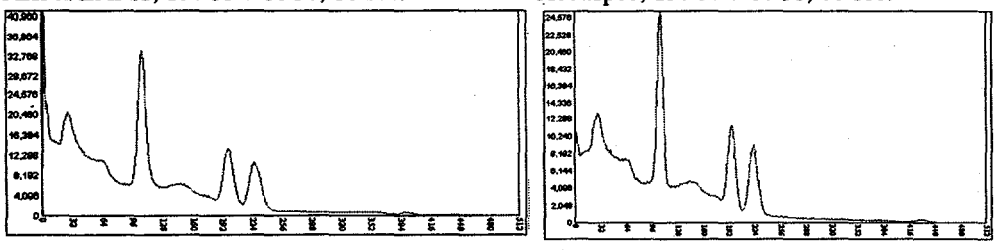

Figure 4. Resolution comparison above 1 MeV between FLIMFLAM1 and Accuspec.

| *Isotope* | *FLIMFLAM1* | *Accuspec* | *Accuspec dead time* |
|---|---|---|---|
| 137Cs | 1,177,000 | 922,000 | 15% |
| 60Co | 1,755,000 | 1,286,000 | 21% |
| Both | 2,567,000 | 1,700,000 | 27% |

Table 1. Performance comparison for 60 second counting time.