Developments in High-Performance HPGe Detector Spectrometer Systems for Safeguards Applications

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Abstract

Both fixed and portable safeguards applications place stringent demands on spectrometer systems. Instruments must perform well spectroscopically despite operation in harsh environments. Resolution and stability requirements for Pu isotopic systems hardware are based on the complexity of the spectrum and the necessity for the analysis software codes to use multipeak regions of the spectrum. Better detector resolution and more stable peak shape/position results in improved precision. Higher throughput is an advantage only if the system remains stable across the count-rate range. If this is achieved, usability is enhanced because of reduced count times, increased sample throughput, and less operator exposure. Choice of software platform is important for: 1) ease of operation, 2) the availability of common tools (spreadsheets, word processors, tool-kits) for application developers, and 3) availability of low-cost PC hardware. Data communication to the PC should be convenient, fast, and reliable, via industry-standard hardware. PORTABLE instrument practicality is further enhanced by factors such as small size, light weight, and long battery life. Two new instruments, one portable and one mains-powered for fixed installations, are described. Both use a common Windows 95/Windows NT software platform. The portable instrument matches the best analog spectrometers in performance, weighs under 5.25 lbs, and operates for over 7 hours without changing batteries. The mains-powered unit is DSP-based, featuring extensive setup automation and greatly improved stability over previous analog designs. Performance data are presented.

Introduction

With the advent of the personal computer in the early 1980s, a new concept in MCAs, of using the PC for control, spectral display, and analysis, was born [1]. The result was the rapid demise of the conventional "one-box" MCA for both in-field and laboratory use.

Today, the universal implementation of MCA systems for laboratory and in-field use is that of a PC (a notebook in the case of a portable system), attached to a "blind" spectroscopy hardware system, in which the PC "emulates" the user-functions of the MCA.

Two of the latest commercial instruments of this type are described, and performance data particularly relevant to the demands of safeguards applications are presented.

The Portable MCA

It is now 15 years since the appearance of the first truly portable Multichannel Analyzer systems for "in-field" spectroscopy.[2] At that time, an in-field system was not expected to provide the performance of a laboratory system. As portable computers did not exist, the portable MCA saved data to magnetic tape for later quantitative analysis.

The "DART", manufactured by EG&G ORTEC represents the latest development in this field. Light and compact, it provides "laboratory-grade" spectroscopic performance in portable/mobile applications. It is ideally suited for use with today's smallest notebook computers, as exemplified by the latest "Libretto" model from Toshiba.

Hardware Description

The portable MCA's block diagram (Fig. 1) shows an Intel 80C188EA microprocessor which controls the amplifier, ADC, and bias supply functions. The amplifier has programmable polarity, automatic pole-zero[3], gain, shaping time, and a gated baseline restorer. Digital stabilization of the amplifier gain and zero offset is provided.

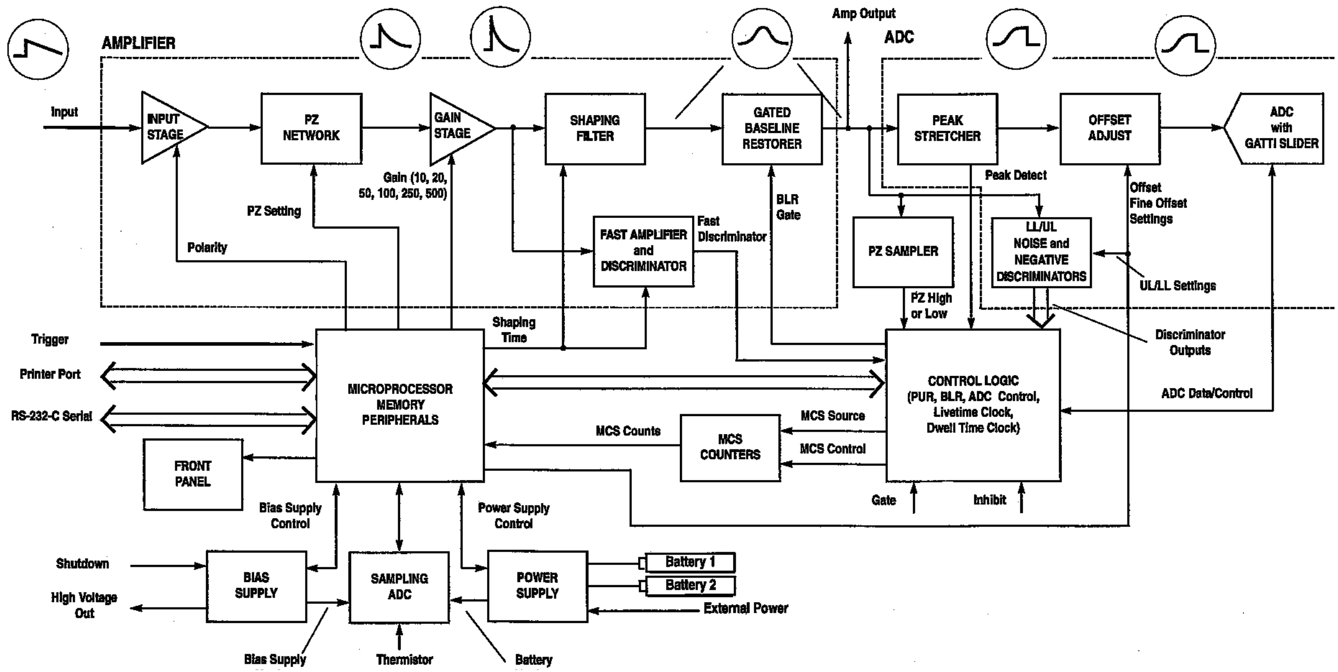

Fig. 1. Block Diagram of the Portable Instrument.

The 13-bit analog-to-digital converter incorporates a Gatti[4] slider. A Gedcke-Hale[5] live-time clock provides dead-time correction accuracy ~3%, even at 50,000 counts/sec input rate. A multichannel scaling mode is included.

A two-mode bias supply supports Ge detectors and also NaI, CZT, or similar detector types. The selection of the bias supply mode automatically selects the step resolution of the digital stabilizer.

A sampling ADC reads the temperature signal from the thermistor in stabilized NaI detectors, for monitoring bias supply voltage and battery condition.

The primary mode of communication with a companion portable PC is via the high speed parallel printer port. Up to eight MCAs may be connected to a single printer port in a daisy-chain configuration, with the system printer remaining always operational.

There are no internal switches or jumpers.

Batteries and Power Management

The unit is powered by two Camcorder batteries, Sony NP97 or equivalent. A standard Camcorder eliminator-charger, may be used to charge batteries or to power the unit. Batteries are hot-swappable with no loss of data acquisition. Seven hours of operation with two fully- charged 3.0 AH batteries and a low-power Ge detector is achievable (50% duty cycle) with no "stabilization wait" before acquisition starts.

Physical

The instrument (Fig. 2), equipped with a sealed-membrane front panel is packaged in a custom plastic case with a clip-in cover to prevent ingress of dust into the battery compartment. All connectors are mounted on the rear panel.

External dimensions are 9.2 cm x 14 cm x 30 cm (3-5/8" x 5-1/2" x 11-3/4"), the weight, including two batteries, is 2.4 kg (5-1/4 lb).


Fig. 2. The Portable Spectrometer.

The DSP-based Gamma Spectrometer

The DSP instrument, available commercially under the name "DSPEC" from EG&G ORTEC is an integrated, mains-powered package, easily connected to existing personal computers, either standalone or networked. The use of digital technology eliminates most of the analog circuitry used in conventional systems, permitting the instrument to achieve superior stability of resolution and peak position. Because it is possible to select from an unusually wide range of filter characteristics, one can choose the exact setting needed to obtain the best possible performance from any detector. A high degree of automation makes this readily achievable.

Hardware Description

The DSP instrument hardware is shown in Fig 3. Following the front-end amplifier, a 14-bit 10-MHz flash ADC samples the incoming pulse stream and converts each pulse into a string of digital numbers. DIGITAL filtering by a proprietary digital filter algorithm (implemented in a Motorola DSP56002 DSP chip set) follows. The filter also provides the functions of digital base line restorer, fine gain, peak qualification, conversion gain, digital upper/lower level discriminators, and digital spectrum stabilizer.

The microprocessor, an Intel 80386EX, controls all system functions, including automatic pole-zero adjustment, and provides a 32-bit, non-volatile spectral data memory of 16,384 channels. It also provides on/off control for the high voltage supply, computer control and I/O via a built-in Ethernet port and control hardware for sample changers. Two secondary means of communication are also provided: RS232C and the ORTEC Dual Port Memory standard. As with the DART, a Gedcke-Hale5 live-time clock is implemented.

Fig. 4 shows the response of the digital filter. It is a near-ideal "Cusp" filter with a variable-width flat-top, which constitutes a quasi-trapezoidal filter. A choice of 32 rise and fall times, 5 flat top widths, and 6 cusp factors are available. An automatic "OPTIMIZE" feature simplifies setup.

Physical

The instrument (Fig. 5) is packaged in a bench-top enclosure with external dimensions 31 cm x 35 cm x 14 cm (12-1/4" x 13-3/4 " x 5-1/2").

Power Requirements

The DSPEC, mains powered, requires 110 watts.

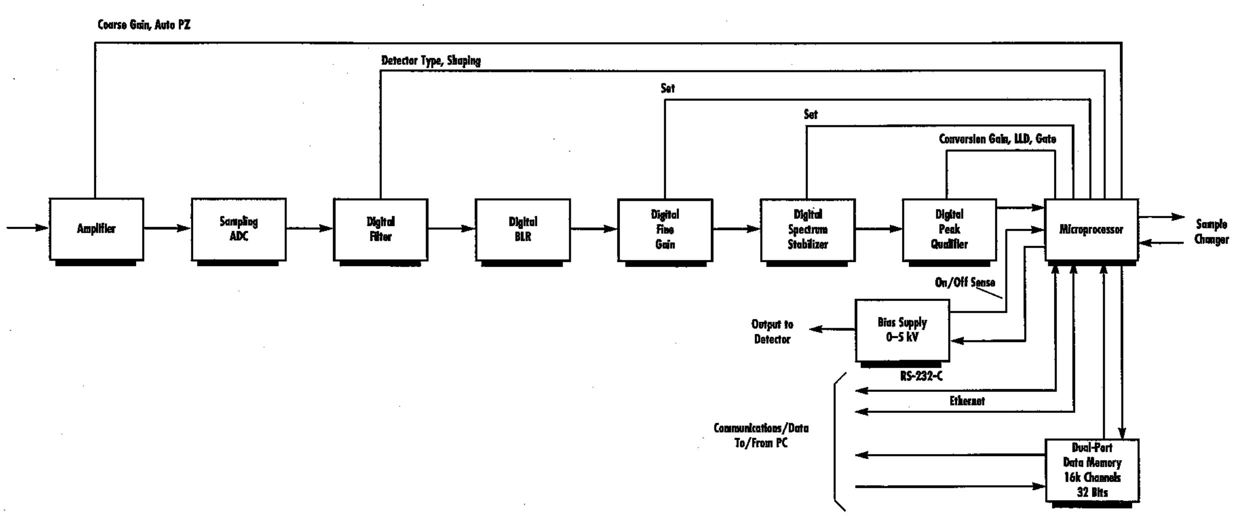

Fig. 3. Block Diagram of the DSPInstrument.

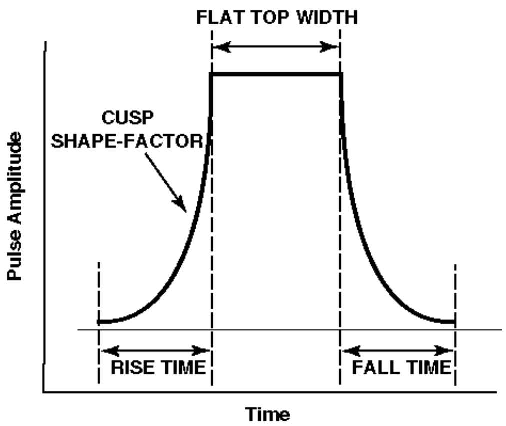

Fig. 4. The DSPDigital Filter Shape.

Fig. 5. The DSPInstrument.

Software for DART and DSPEC

Both DART and DSPEC are supported by a choice of 16- or 32-bit EG&G ORTEC standard MCA emulators and analysis packages, for operation under Windows®, Windows 95, and Windows NT. In the case of the digital instrument, this includes an oscilloscope emulation mode which allows the user to observe, via the PC, the synthesized analog representation of the filter, correct adjustment of the digital PZ adjust, BLR, etc. Safeguards-specific applications are available for use with these instruments: MGA++, PC/FRAM and Isotopic. A Programmer's Toolkit aids developers, allowing a single application to be run on either of these or other related hardware products without modification.

Comparative Performance Data and Discussion

The most commonly used germanium spectrometer found in safeguards applications is the planar detector. Measurements were made with both instruments and an EG&G ORTEC SG-GLP Safeguards planar detector of 1000 mm^2 area, on the 122-kev ^{57}Co peak.

In most Safeguards measurements, it is desirable to operate in a regime in which the count-rate into memory (system throughput), is as high as possible, while the parameters of detector resolution, resolution stability with count rate, peak shape stability, and peak position stability are as good as possible, thereby achieving, in the shortest possible time, the best result! Counting at or near the throughput maximum will result in the minimum possible time to count to a given precision. Counting at a rate above this maximum increases the time required. The demands of high throughput and best performance with respect to the parameters above require that compromises be made.

The specialist codes typically used for Isotopic plutonium measurements below 300 kev all require that a stable detector resolution of 550 to 650 eV be achieved if results are to have a precision ~1% or better.

The Benchmark

To establish a benchmark, a premium "standard NIM" system was configured consisting of an EG&G ORTEC Model 921 ultra-high speed multichannel buffer and a 672 spectroscopy amplifier, operating in triangular-filter mode. The ORTEC 672 is often used in independent tests for bench-marking purposes. The 921 incorporates a 1.5-ms fixed conversion time ADC, which is fast enough not to limit the system throughput even at shaping times as low as 1 ms.

Results for Both Units

Throughput and Resolution

Fig. 6 shows comparative throughput data. It is seen that the DSP system at settings of 1.6 us and 0.8 ms have significantly higher throughput maxima than that of the NIM system with triangular filter of 1 ms, and in which the ADC, at 1.5-ms conversion time is contributing nothing to system dead time. The Portable unit has a maximum throughput of 28,000 cps. The reduction from the figure of 44,000 cps of the NIM system is entirely due to the use of a 12-ms fixed conversion time ADC in the portable instrument, a tradeoff made for reduced power consumption.

At low rates the 8-ms setting of the DSP system corresponds in throughput almost exactly with the 3-ms NIM settings. Note that the DSP throughput curves are flatter than the analog curves, and that the 2-ms Portable curve almost comes down to meet the 8-ms DSP curve at 120,000 counts per second.

Fig 7 shows the resolution data. The Portable's 1-ms resolution data is essentially IDENTICAL to the 1-ms NIM data. At 2 ms, while losing out by about 10 eV at low rates, the portable actually shows BETTER resolution and resolution stability above 80,000 counts per second! (The dead time of the portable unit at 2 ms and 80,000 cps is 80%). Even for an input count rate of 120 kcps, it achieves a resolution of 601 eV.

The 1.6-ms DSP data shows resolution close to the 1-ms Portable and 1-ms NIM systems, but with the benefit associated with the additional throughput shown in figure 6.

The 0.8-ms DSP data is outside of the resolution range normally associated with Safeguards accountancy measurements for which isotopic ratios must be determined to precision of ~1%. As was stated recently[6], inaccuracy of as much as 20% are acceptable in some waste assay applications, and the extra 64% in throughput compared to the 1-ms NIM system is valuable for some applications.

The NIM 3-ms and DSP 8-ms comparison shows for low to moderate count rates, how the DSP system delivers the ultimate resolution performance with much better resolution stability than the nearest comparable analog system (3-ms NIM).

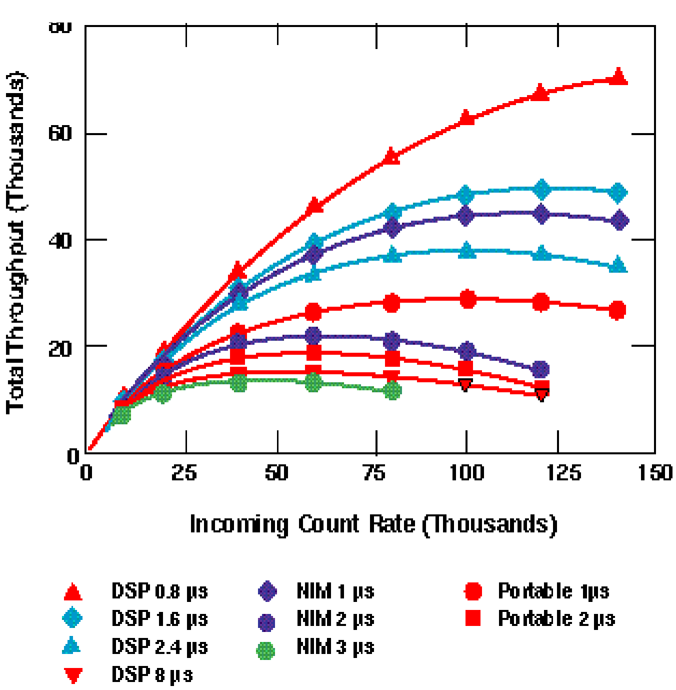

Fig. 6. Comparative System Throughput.

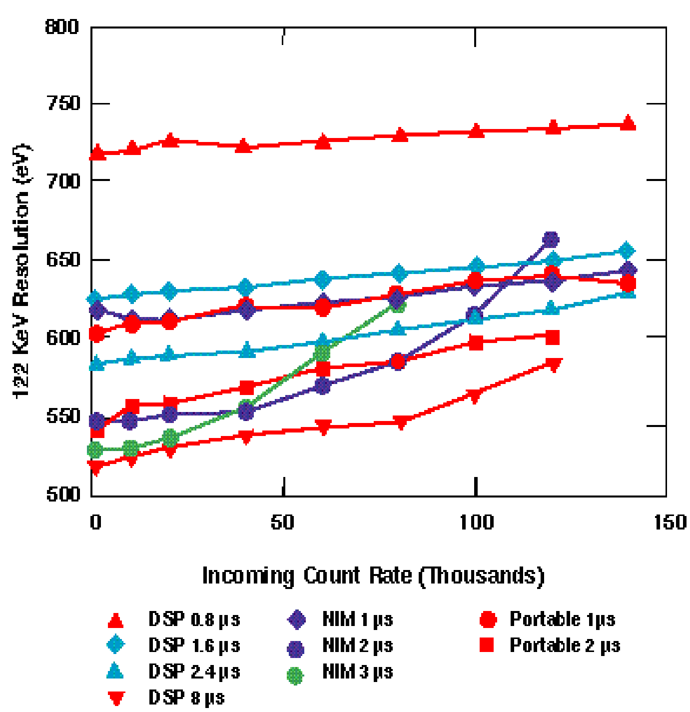

Fig. 7. Comparative System Resolution.

Peak Shift

Fig. 8 shows the peak shift data. For both instruments the peak shift performance is excellent under all counting conditions measured. The portable instrument shows a worst case peak shift of just over 0.05% at 140,000 counts per second, the NIM system showing a worst case peak shift of approximately 0.02% at this count rate. The DSP data shows even better stability, the worst case value being just over 0.01% at 140,000 counts per second.

In particular, the DSP at 8 µs shows much better stability than the benchmark NIM at 3 µs, which is equivalent from a throughput standpoint. At all settings measured, the DSP system proved more stable than the premium NIM analog system.

Peak Shape

For the various Isotopic codes to operate optimally, it is extremely important that the peak shape for gamma rays remain Gaussian and stable with count-rate. This determination was made by measuring on the 122-keV peak, the ratio of the FW.1M (full width at 1/10 maximum) to the FWHM (full width at 1/2 maximum. A perfect gaussian shape would give a ratio of 1.83. In all cases performance is seen from figure 9 to be excellent.

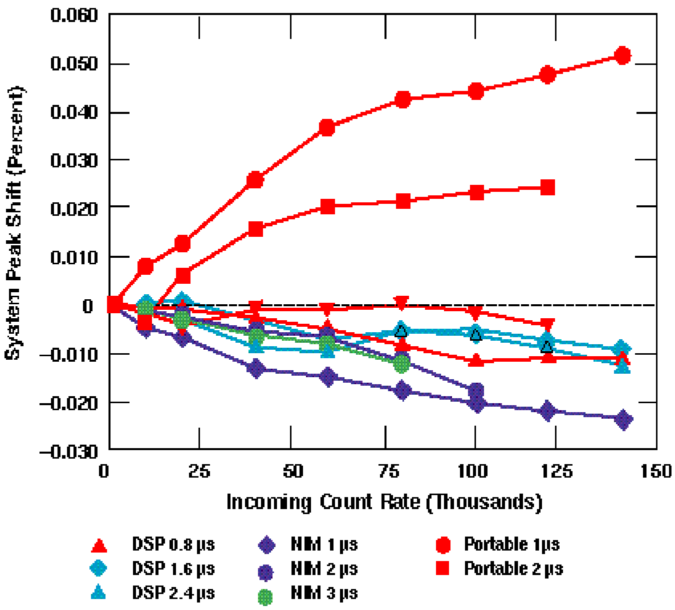

Fig. 6. Comparative System Peak Shift %.

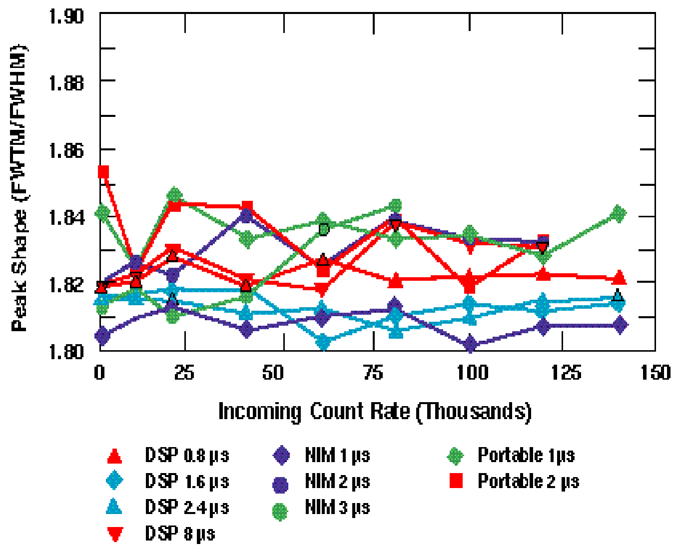

Fig. 6. Comparative System Peak Shape FWTM/FWHM.

Conclusions

Two new spectroscopy systems applicable to safeguards applications, have been evaluated. The Portable MCA system has been shown to provide comparable or better performance compared to a premium NIM analog system, the sole exception being the ultimate throughput. The portable system maximum throughput, although lower than the NIM system, is higher than similar portable MCAs, over which it offers additional advantages in terms of reduced weight and longer battery life.

The DSP system has been shown to provide more desirable tradeoffs between resolution and throughput, while also achieving substantially enhanced stability.

The data demonstrate:

For ultimate resolution at low rates, the DSP system is superior;

For maximum throughput, the DSP system is superior;

For stability of resolution and peak position, the DSP system is superior.

If a portable system is mandated by the application, then the portable system described here only compromises on throughput, when compared with the benchmark premium NIM system. In all other respects it is equivalent, being surpassed only by the DSP system.

These two instruments, DART and DSPEC, deserve consideration for Safeguards isotopic measurements.

Acknowledgement

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