Performance of a portable, Digital-Signal-Processing MCA with Safeguards Germanium Detectors

Bingham, R. D., Keyser, R. M., Twomey, T. R.
ORTEC, PerkinElmer Instruments, Inc
801 South Illinois Avenue
Oak Ridge, TN 37831

Abstract

The use of digital signal processing (DSP) has become the standard for high-performance laboratory instruments for measurements in the field of nuclear spectroscopy. In all applications it offers greater stability, improved resolution and greater throughput at high count rates compared to analog or traditional designs. All of these improve the quality of the spectrum and the analysis results. Safeguards applications, especially the isotopic-ratio calculation, depend on the high resolution and stability of the MCA and detector for accurate results. Recently, advances in low-power DSP modules have made it possible to incorporate DSP in useable, portable instruments. A portable multichannel analyzer system consisting of a HPGe detector, with integral bias supply, and a MCA has been developed. This system includes all the benefits of digital processing in a complete instrument for spectroscopy. In addition, the unit includes a local display and keypad, to eliminate or significantly reduce the need for a PC in many field applications. When used with the associated "intelligent" HPGe detector system, the instrument monitors 18 operating parameters of the system, including detector temperature, to derive the overall system state of health. In addition, the unit provides authentication of the entire system and the collected data. The system has been tested using both liquid-nitrogen and electrically cooled detectors. The peak position and resolution have been measured using the commonly available mixed nuclide sources. Performance data for peak resolution and position vs countrate, peak resolution and position vs time, using Safeguards-quality HPGe detectors will be presented.

Introduction

Since their introduction, DSP-based Gamma-ray spectrometers have become the “industry standard” and are now widely used both “standalone” and within larger measurement systems. It has rapidly become clear that the DSP technology had no performance disadvantages relating to spectroscopy; indeed, in every case, they have shown to offer improved resolution, throughput and stability, both over long time periods and wide temperature changes. The wide choice of operating parameters coupled with a high degree of setup automation available, in some cases, means that the instrument performance is easily “tuned” to make the optimum use of this performance in a specific application situation. Not surprisingly, a wide variety of systems have been developed incorporating these digital spectrometers, in counting laboratories, remote monitoring, industrial on-line applications and non-destructive assay applications. DSP systems are proving capable of meeting the most demanding of applications.[1]

The recent arrival of low-power, digital-signal processing technology has now made it feasible to incorporate the high performance expected of a digital spectrometer into a small, battery-operated package. The portable DSP systems can show equivalent performance to the laboratory based instruments, as we shall see.

From a historical perspective, introduced almost 20 years ago, the LANL-developed Davidson PMCA[2] with on-board cassette tape storage, local display and some limited "smart" capabilities has been the instrument of choice for safeguards inspectors across the world. It has been used for routine measurements such as uranium enrichment for many years; it still provides a unique combination of features in a single integrated and portable package. Many hundreds are currently in use. Its attraction is in its combination of useful features:

Battery Operated
On Board Display and spectral data storage
Full work shift operation (more than 10 hours) without change of battery
"Good quality" spectroscopy (for a 1982 vintage portable system)
Ability to do some calculations without an attached PC.

Until now, the recent-generation of small portable MCAs, have no on-board bulk storage, display, keypad or computing power and are "blind peripherals," they require the use of an associated small computer.

The new instrument reported here, with the trade-name digiDART™ is being produced by PerkinElmer Instruments (ORTEC). It combines the high performance attributes of the digital signal processing in a small, low-power, battery-operated package. The instrument includes an on-board display and the ability to store multiple spectra without the need for an accompanying PC. It can be viewed as a state-of-the-art-technology successor to the PMCA. In addition, the instrument includes new "SMART-1" HPGe detector technology, which can monitor the system "state of health" and provide authentication of spectral data, very valuable in remote or unattended monitoring in a single instrument. Therefore, it can address a variety of existing and developing use needs. The wide range of applicability means that this instrument can help reduce the inventory of different MCA types required to support the spectrum of safeguards applications.

Circuit Description

The MCA hardware is shown schematically in Figure 1. The high voltage supply and detector monitoring are provided in a separate detector interface module (DIM). Following the front-end amplifier, a 14-bit, 10 MHz flash ADC samples the incoming pulse stream and converts it into a string of digital numbers. This is then filtered directly by a proprietary digital filter algorithm, implemented in a field-programmable gate array (FPGA). This also provides the functions of digital baseline restorer, fine gain, peak qualification, conversion gain, digital upper and lower discriminators, and spectrum stabilization. System control, keypad communications, spectral display and control of USB and/or RS232 communication is provided by the microprocessor. The microprocessor also controls the detector high voltage and provides the detector monitoring function. The battery-backed histogram memory provides up to 16,000 channels of non-volatile data storage with optional 32,000 channels. A flash memory provides for non-volatile storage of multiple spectra. Over 600 512-channel spectra may be stored. A digital version of the Gedcke-Hale[3] live-time clock is implemented.

The digital trapezoidal filter provides 99 rise time (RT) and 16 flat top (FT) choices in the ranges 0.8 µS to 20 µS and 0.3 µS to 2 µS respectively. This range of choices is wider than other DSP units to allow precise optimization of detector settings. A digital Automatic Pole Zero circuit[4] is provided, along with an optimize function to automatically optimize the flat top tilt as well as Pole Zero across the range of rise time/flat top combinations.

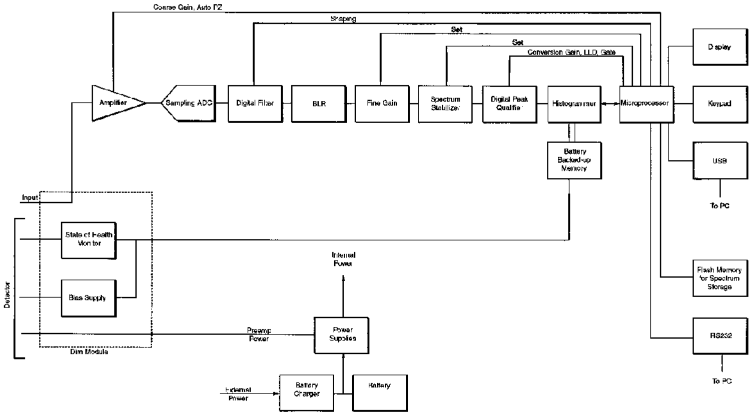

Figure 1 Portable MCA Schematic Block Diagram

Battery and Power Management

The instrument is powered by a single Sony NP-F960 camcorder battery, which will operate for up to 12 hours including supplying the detector power. The battery may be replaced without loss of spectral data and the instrument restarted in seconds. The battery management circuitry is built into the instrument. Any 12V DC external supply will charge the battery and operate the instrument.

Physical

The instrument is packaged in an impact-resistant, ABS plastic enclosure, with rubberized overmolding, as shown in Figure 2. The outside overmold is a shock-absorbing, easy grip, stay clean coating. The display and sealed membrane keypad are recessed to protect them if the instrument is dropped. The easy-to-grip enclosure will fit in a box 20 cm x 12.7 cm x 7.7 cm and the weight including battery is <850 gm.

Figure 2 The portable MCA in hand-held use

Display and Built-in Analysis functions

The 240 x 160 pixel backlit LCD (Figure 3) provides live spectral display, status information and analysis results. It features full display, display of multiple ROIs and Zoom modes.

A Status line provides parameter display; with the user able to choose any two from: cursor energy, location, live time, live time remaining, real time remaining, battery life remaining, Count rate, Count rate in ROI, or counts. A real time Peak Information function reports centroid, FWHM, Net and Gross area for the ROI where the cursor is positioned.

A two-point energy calibration of channel and FWHM can be done at any time from the keypad. The user can define from 1 to 9 regions for the Nuclide activity display. The activity with uncertainty is calculated and reported in real time. Multiple acquisition presets are provided: live time, real time, integral peak count, peak area, MDA and uncertainty.

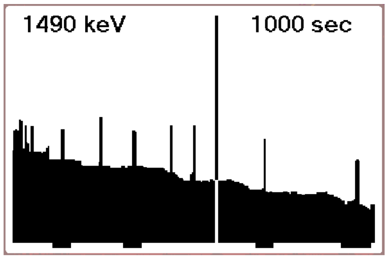

Figure 3 The portable MCA spectral display

SMART-1 HPGe Detector Support

The MCA supports HPGe detectors with the SMART-1 technology, as well as “traditional” HPGe detector systems. The SMART-1 HPGe detector supports many advanced features, as described in another paper[5].

Associated Software

The unit is supported by the ORTEC standard MAESTRO™ MCA Emulator. The easy setup has been extended to support all the instrument functions via the USB hardware interface. All of the setup can be done by MAESTRO or by the standalone digiDART. The philosophy is that it is easier to setup the instrument for use “back at base” using a large-screen PC, but all the settings may be changed in the field, where there is no PC available.

The settings can be protected by password, so the settings can not be inadvertently changed. Two levels of passwords are used to allow different levels of access control. If either level of password is set, the password must be entered when the MCA is powered on.

The instrument is compatible with all of the ORTEC analysis packages, including versions of MGA++ and PC/FRAM Isotopic ratio packages, and products for the ISOTOPIC analysis of soils and containers as well as general purpose gamma-analysis packages. To assist the developers of custom or in-house systems, programmer toolkits are available[6].

Performance data

In a recent LANL evaluation[7], the latest ORTEC digital laboratory spectrometer, the DSPEC Plus was evaluated and considered to be “highly recommended.” It may therefore be considered as a suitable digital benchmark for comparison purposes. The ORTEC 672 Spectorscopy Amplifier has long been considered as a performance benchmark for use in analog systems. In figure 4, the digiDART performance was compared to the DSPEC Plus and an analog system incorporating the 672 and a Canberra 8076 450 MHz Wilkinson ADC under conditions which are similar to those pertaining to many safeguards measurements. The data were taken with an ORTEC 500 mm^2

safeguards planar detector[8].

The data in Figure 4 show clearly that the DigiDART is capable of equivalent performance to the highest quality lab systems, both analog and digital. Even at 100 kHz input rate, the peak FWHM from the digiDART is 600 eV, which meets the stringent requirements of the isotopic codes such as PC/FRAM and MGA. At 100 kHz, the Digidart shows almost 10 and 51% higher throughput than the DSPEC + and NIM Analog systems respectivley, with almost equal resolution (only 1.5% or 9 eV worse than the NIM system).

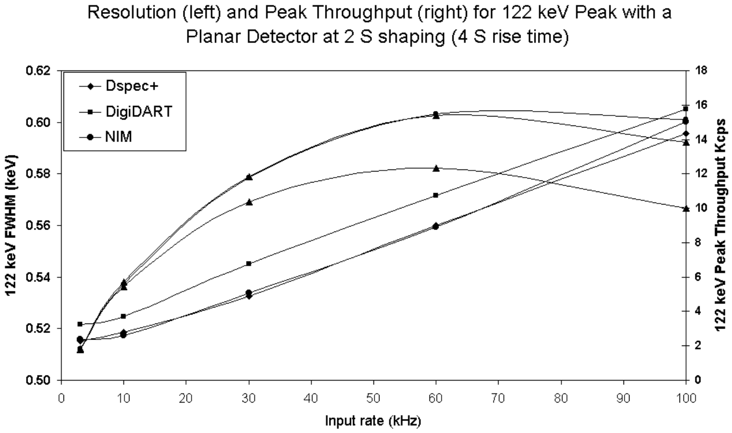

Figure 4

Measurements were also made with an ORTEC Safeguards GEM 25, 25% relative efficiency, coaxial detector with the following warranted specifications:

Model	Active Diameter (mm)	Thickness (mm)	Energy (keV)	FWHM @ 1 kcps (6 µs shaping)	FWHM @ 1 kcps (2 µS shaping)	FWHM @ 30 kcps (2 µS shaping)
SGD-GEM-25175	50	50	122	750eV	870 eV	880 eV
			1332	1.75Kev	1.95 keV	2.0 keV

The **SGD-GEM** detector type was developed specifically to meet the needs of PC/FRAM in high-energy mode. A smaller version of this detector has recently been tested for use with MGA in so-called 2-detector mode, with successful results[9]. This detector and a larger nominally 50% relative efficiency type have been specified for use in the Los Alamos Tomographic Gamma Scanner (TGS)[10].

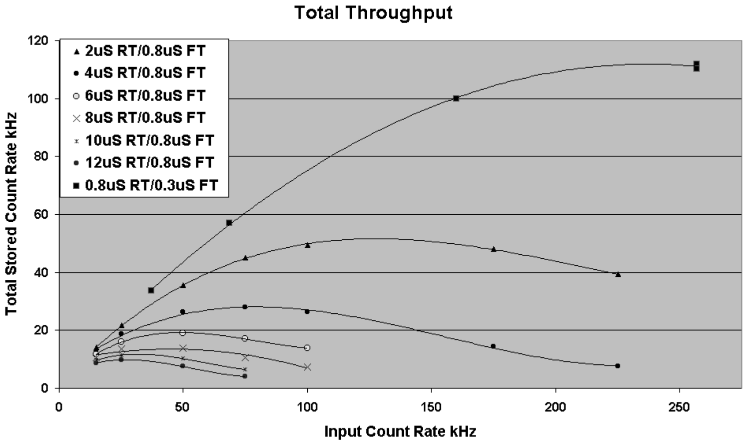

Figure 5 Total system throughput performance: coaxial detector

Figure 5 shows total throughput curves as a function of input count rate. All except the upper curve were measured with an 0.8uS filter flat top The upper curve was measured with an 0.3uS flat top to demonstrate the ultimate throughput of the system to exceed 100KHz. This produced a 122keV peak with a resolution of 3KeV (not shown) , which was very stable in FWHM and in position with increasing count rate. While of academic interest here, such a performance trade-off may be valuable elsewhere, where throughput is more important than resolution.

Figure 6 shows that the system resolution performance meets the coaxial detector warranted 1KHz count rate performance specifications of 870 eV at 2uS shaping (4uS risetime) even at 30 kHz. The resolution is seen to degrade towards shorter shaping times due to the charge collection time in the coaxial detector crystal being longer than the integration time.

Figure 7 shows the variation in 122 keV resolution with count rate and rise time.

In general, the shorter shaping times give poorer resolution and better stability as would be expected.

For the 4 µS data, even at the point of maximum throughput of 28 kHz at 75 kHz input rate (Figure 5), Figure 7 shows that the resolution at 900 eV is only 20 eV worse than the detector warranted value at 30 kHz input rate.

Figure 8 shows peak shift versus count rate. The stability for short shaping times is better, the tradeoff being resolution.

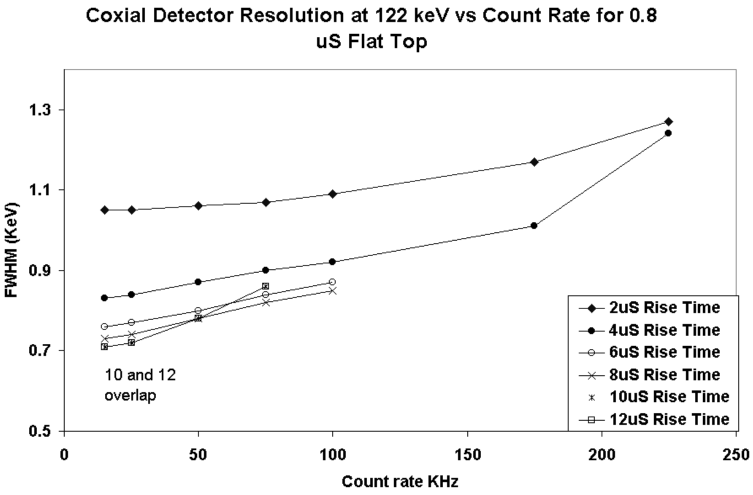

Figure 6

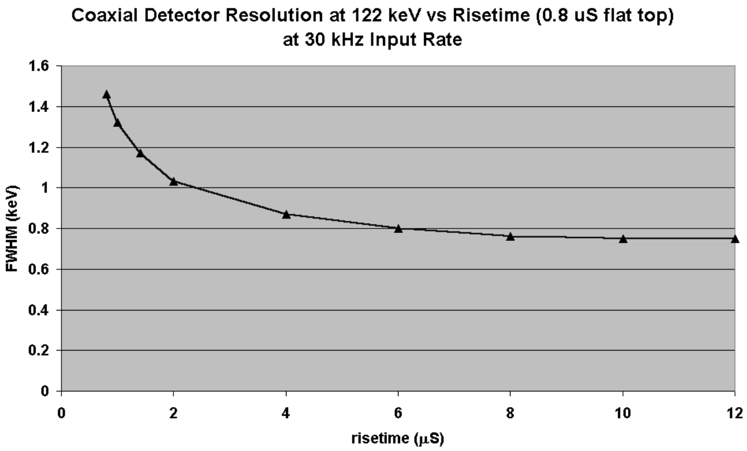

Figure 7

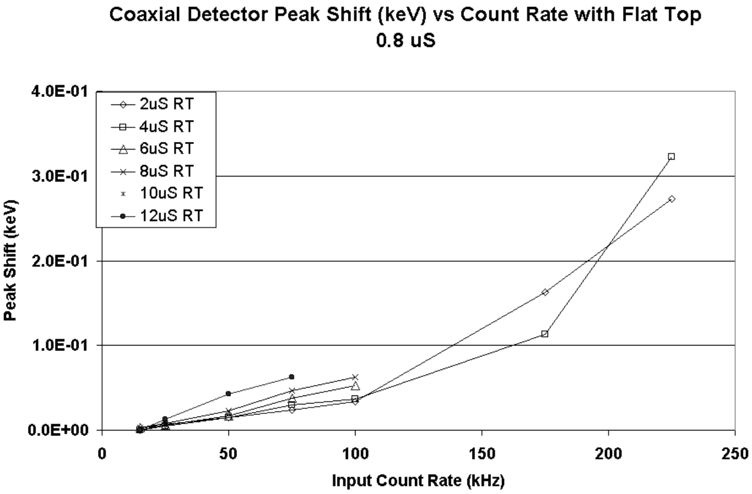

Figure 8

The implication of figures 5-8 is the following: The resolution requirement in a spectroscopy problem is defined by the complexity of the spectrum, especially true in isotopic ratio measurements. This defines what shaping time must be employed for a give detector. The question may then arise as to how fast data may be taken, (how quickly can the measurement be made), or over what range of count ratescan the system operate without excessive peak shift or resolution degradation. (The optimum count rate to take data is the point of maximum throughput). What is shown here is that the digiDART makes it possible to "fine tune" filter settings to the best effect, and that once done, the count rate stability is excellent.The system continues to produce viable data from low rates to beyond the point of maximum throughput, with peak shift of less than 40 eV (0.03%) across the range.

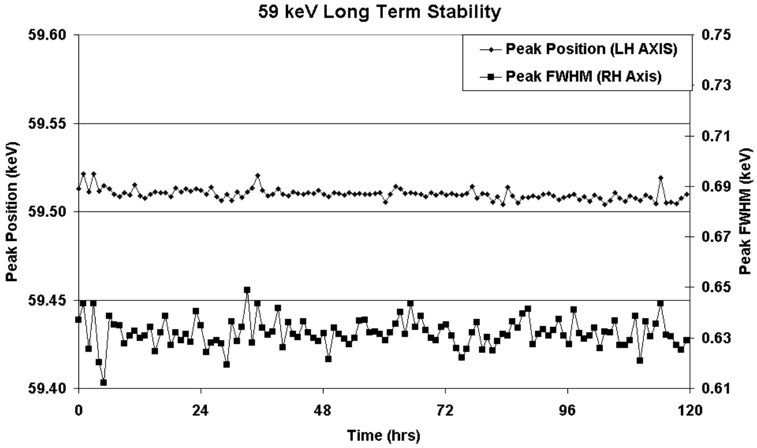

Figure 9

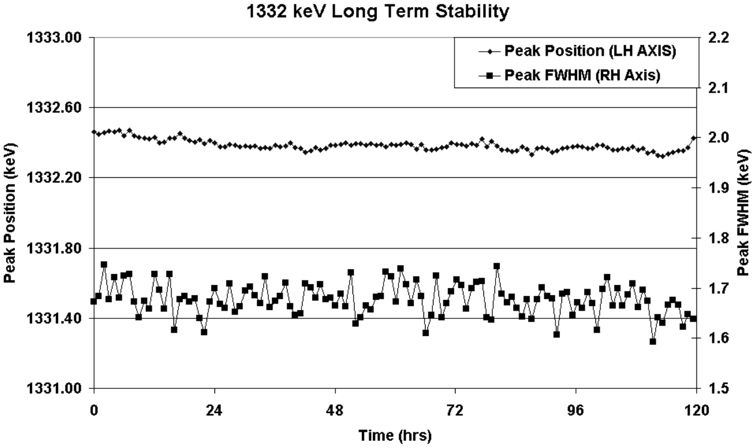

Figure 10

Figures 9 and 10 show peak position and resolution at low- and high- energy over time. A mixed isotope source was acquired over a period of 5 days: 120 spectra. The count-rate was approximately 1 kHz. The filter setting was 12 μS risetime, 0.8 μS flat top. The 59 keV and 1332.5 keV peaks were monitored.

At 1332 keV the peak position and resolution drift standard deviations were 0.002% and 2% respectively, while at 59 keV the corresponding results were 0.005% and 0.9%.

Conclusion

A new and innovative digital high performance portable MCA has been developed and tested. In spite of the demands of designing for low power, it has been shown to provide performance at least equivalent to the best laboratory grade, digital spectrometer and the best analog systems. In practical terms there is no longer any trade off in performance for a field system. Indeed this system can be effectively used in fixed installations, where small size/low power, battery backup, local multiple storage, networkability, detector self-diagnostics and data authentication can be assets to the measurement. Its packaging and display provide superior ergonomic features, whereas multi-spectral storage and analysis capabilities extend the usefulness of handheld MCAs.

Acknowledgements:

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