Portable Radiation Spectrometer Using Low Power Digital Pulse Processing

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Abstract

A portable radiation spectrometer was developed based on real time digital signal processing. A single chip, low power digital pulse processor incorporates the trapezoidal pulse shaper, a fast discriminator, base-line restorer, peak detector, pile-up rejector and the data acquisition circuitry. The processor operates at 25 MHz clock speed and has active power consumption of less than 600 mW. The front-end electronics provide analog signal conditioning and data conversion with power consumption of less than 600 mW. The spectrometer is powered by a single battery, exploits a USB interface and fits in a small package with dimensions 15x18x3.8 cm.

I. INTRODUCTION

The digital signal processing of the signals from radiation detectors is becoming a technique of choice and is gradually replacing the traditional analog pulse processing methods [1,2]. Digital pulse processors offer various advantages over the analog counterparts – true trapezoid pulse shaping, noiseless signal manipulations, improved temperature stability, flexibility and versatility. Recently, the digital pulse processors have also become commercially available as bench-top units [3,4]. Until now, an area which has not been exploited and has not benefited from digital pulse processing technology is portable instrumentation. The purpose of our work was to develop a low power, portable spectrometer that utilizes digital signal processing. This paper describes the main features and the low power design approach for this new class of portable spectrometers. A detailed description of the spectrometer functional blocks will be presented elsewhere.

II. SPECTROMETER CONFIGURATION

The design of a portable spectrometer requires that the electronics use low power and are sufficiently small to be enclosed in a small package. In addition, small size and low power consumption should not limit spectrometer performance. Our goal was to develop a portable digital spectrometer that fits in a small package with dimensions 15x18x3.8 cm. The spectrometer, with a commercial name of InSpector 2000 is depicted in Fig. 1. In order to develop a small portable spectrometer, a number of obstacles have to be overcome.

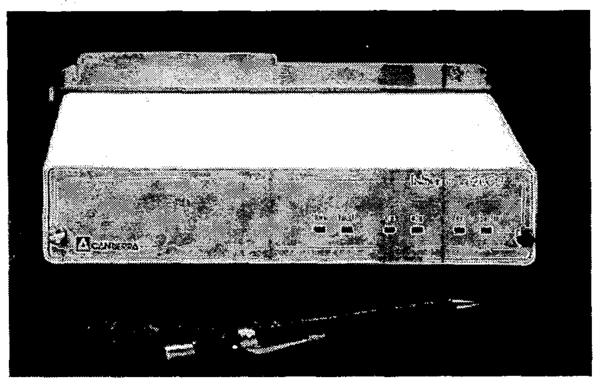

Fig. 1. Portable digital spectrometer.

One of the obstacles in using digital signal processing techniques for portable spectrometers is power consumption of the high-speed digital electronics. Until recently, real time digital signal processing functions were distributed among several chips with medium to high density. These chips were clocked at relatively low rates and still required significant power. Normally a large number of bits change their state at each clock cycle. Due to the capacitive loads of the device terminals and the interconnecting traces the dynamic power consumption usually exceeded a few watts. Therefore, in order to reduce the power consumption, it is necessary to reduce the load capacitance. That is, if possible, all high-speed data buses have to be connected inside of the same chip.

Another factor that directly affects the power consumption is the supply voltage of the digital signal processing circuits. The supply voltage determines both the static and the dynamic power consumption. The 5 V interface has been a standard for decades but the use of lower voltage is essential for the low power design.

With the recent advances of sub-micron technology silicon chips with operating voltages of 3.3 V, 2.5 V down to 1.8 V have become available. In addition these chips offer high speed and high transistor densities. These advances have become essential in the area of the field programmable gate arrays (FPGA). High density, low voltage FPGAs are available that allow a system on chip implementation.

We developed a digital pulse processor that fits in a single chip FPGA. An Altera high density, low power

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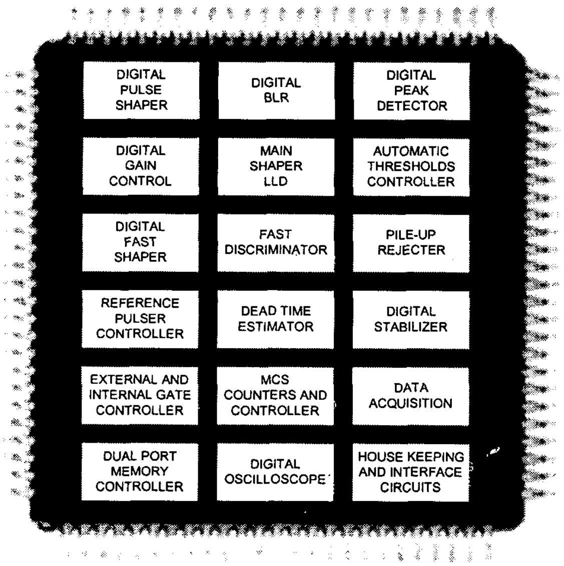

Fig. 2. FPGA functions of the digital pulse processor.

FPGA was chosen because of its high speed (>100MHz), high density (>100k gates), and low power consumption (2.5V core and 3.3V interface voltages). Fig. 2 shows the main functions implemented in the FPGA. The digital pulse processor incorporates two real time digital shapers [2]. The main pulse shaper (slow shaper) produces trapezoidal/triangular pulses with rise time from 400 ns to 40 μs. The flat top can be adjusted from 0 to 3.2 μs. The rise time and the flat top are adjusted in increments of 80ns. This shaper serves the pulse height measurement channel.

The other shaper (fast shaper) is a part of the fast discriminator chain. The fast shaper can produce rectangular, triangular and trapezoidal pulses. The width of the fast shaper is adjustable from 160 ns to 10 us. The width is optimized to match the detector type and slow channel rise time selection. The fast discriminator has a digitally controlled threshold that can be set automatically or manually.

Each of the shapers has a digital base-line restorer. The output of the slow shaper feeds an innovative digital peak detector. The digital peak detector is optimized for fast operation with minimal noise sensitivity. The digital peak detector will be described in a separate paper. The detected and captured pulse peaks are used for pulse height analysis.

Another feature is the digital oscilloscope function. The digital oscilloscope allows observation of the waveforms of the slow and fast shapers. It also supports mixed mode of operation. That is the analog waveforms are displayed simultaneously with four logic analyzer traces. The logic traces can be the pile-up rejector signals, peak detector signals, gates, and discriminator logic traces. This feature allows observation of the slow shaper to assist with setup.

The FPGA design also supports the pile-up rejection circuit, various supporting functions for automatic adjustments, and the data acquisition system. The pulse processor operates in real time at a sampling rate of 25 MHz. The only data bus that is clocked at this speed and is connected externally to the FPGA is the data from the fast ADC. All other data buses are internal to the FPGA, thus the dynamic consumption of the processor is maintained to a minimum. By optimizing the logic and utilizing efficient algorithms, we were able to achieve power consumption for the processor of less than 600 mW.

Another important requirement to achieve low power is the analog front end. We developed a low power front-end electronics subsystem that conditions the analog signal. The signal from the preamplifier is applied to a buffer amplifier. After differentiation the signal passes through a digitally controlled amplifier. The amplifier has adjustable gain from 1 to 1024. The gain is adjusted in coarse, fine and super-fine steps. The amplifiers are powered by ±5 V.

Pole-zero, overload protection and ADC base line stabilizing circuits are also part of the front-end unit. The signal polarity controller allows selection of either positive or negative input signal. The conditioned analog signal is digitized by a 12bit 25MHz fast ADC. The ADC is powered by +5 V for the analog section and +3.3 V for the digital interface. The power consumption of the front-end electronics is less than 600 mW. Fig. 3 depicts the major functional blocks of the analog front-end board.

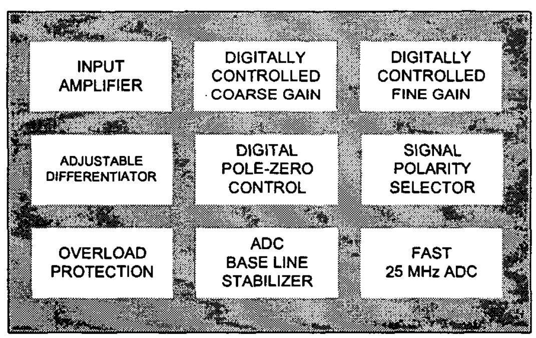

Fig. 3. Analog front-end.

The FPGA is connected to memory for storage of accumulated spectra and to two microcontrollers. The average speed of these interconnections is less than 1 MHz that does not cause a significant dynamic power consumption. One of the microcontrollers is used to support DSP functions in the FPGA while the other (main) synchronizes and controls the operation of the entire spectrometer.

The flexibility of the digital pulse processor and an innovative data acquisition system allows the spectrometer to operate in different modes – pulse height analyzer with resolution of up to 16k channels, single channel analyzer, multiple window discriminator/integrator and multi-channel scaler with programmable acquisition parameters.

The versatility of the digital spectrometer requires fast and reliable data transfer. A USB interface was incorporated to achieve a fast data transfer from the spectrometer to the host computer. The USB function supports the plug-and-play feature. A serial RS-232 port is also supported. In order to accelerate the data transfer through the RS-232 link, a compression algorithm was developed. This algorithm will be described elsewhere. Fig. 4 shows the main digital functions outside the FPGA.

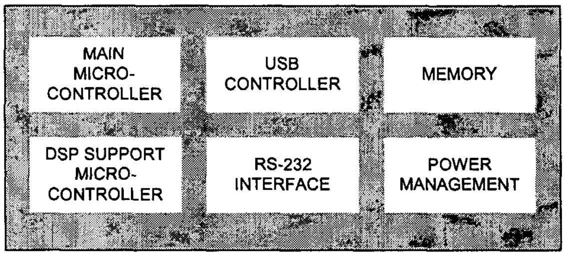

Fig. 4. Digital functions outside the FPGA.

The low power consumption and long battery life of the portable spectrometer also depends on the efficiency and performance of the low voltage and high voltage power supplies. The InSpector 2000 was designed to work with a variety of radiation detectors. Thus, it is necessary to support the standard preamplifier power supply specification as well as the high voltage requirements.

The portable spectrometer can be used with a variety of detectors in the field – HPGE, NaI, CZT etc.. The bias voltage for these detectors is provided by an efficient, digitally controlled, high-voltage power supply. Fig. 5 depicts the main blocks of the portable spectrometer power supply.

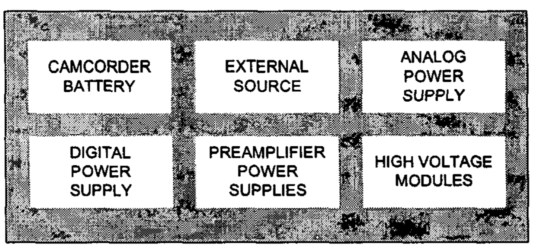

Fig. 5. Power supply functional units.

III. Spectrometer Characterization

Several prototype Inspector 2000 units have been built and tested to characterize performance. The results presented here are preliminary and should not be used as characteristic data for commercial InSpector 2000 product. The InSpector 2000 data sheet is available from Canberra Industries, Inc. The main goal of the tests was to compare the performance of the portable digital spectrometer with a commercially available analog portable spectrometer, the InSpector.

One of the major advantages of the digital spectrometers over the analog counterparts is the improved throughput rate with a good energy resolution. For example, a test performed using a HPGE detector at 30kcps interaction rate showed throughput rate of 21kcps for the digital spectrometer versus 5.7kcps throughput rate for the analog Inspector. The rise time of the digital trapezoid filter was 5.6 μs and flat top of 800 ns. The shaping time constant of the analog Inspector was 4 μs. Maximum throughput rates exceeding 100kcps have been demonstrated with this portable digital spectrometer. Note that the digital spectrometer not only has a higher throughput rate but also shows a better energy resolution (Co60 source) 1.82 keV versus 1.96 keV for the analog Inspector.

Other tests were performed to evaluate the first prototypes. The thermal gain drift over the 0 to 50°C range was measured at about 50ppm/°C while the zero drift was undetectable (<1ppm/°C) over the same temperature range. Battery life tests have shown 10-12 hours of continuous operation from a single rechargeable battery. USB data transfer rates of less than one second have been demonstrated for 8k channels of data. In general, the comparison of the digital spectrometer with benchtop digital spectrometer indicates similar performance characteristics.

IV. Conclusion

We have developed a spectrometer that is a part of a new class of miniature radiation instruments. The spectrometer is based on a single chip, digital pulse processor and has features that have not been previously available in low power portable spectrometers. The preliminary measurements and evaluation tests indicate performance similar to the high-end bench-top digital spectrometers.

V. References

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