Enhanced 8K Pulse Height Analyzer and Multi-Channel Scaler (TUKAN) with PCI or USB Interfaces

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Abstract – We present two types of 8K-channel devices designed for spectroscopy or intensity vs. time measurements. The first one (Tukan-8K-PCI) can be plugged into a PC slot and is based on a PCI Interface. The second type (Tukan-8K-USB), based on a USB interface, is contained in a screened separate box and can be powered either directly from the USB port or from an external DC source (wall adaptor or battery). Each type of device may work in two independent operational modes: Multi Channel Analysis (MCA) and Multi-Channel Scaling (MCS). The crucial MCA component – Peak Detect and Hold circuitry - is featuring a novel architecture based on a diamond transistor. Its analog stage can accept analog pulses with front edges down to 100 ns and has a differential linearity below 1% (full scale sliding scale averaging). Automatic stops on count in Region-Of-Interest (ROI) and on preset live or real time are implemented. The MCS works at medium speed counting rates (up to 8 MHz), with preset dwell time, number of channels and multi-sweep mode. Each these parameters can also be controlled externally. Digital interfacing is based on four user configurable logical I/O lines. A single FLEX10KE30 Altera FPGA provides all control functions and incorporates PCI interface. The USB communication is based on FTDI FIFO controller. The analyzer is equipped with advanced, user-friendly software [1], which is subject of another publication.

I. INTRODUCTION

SINCE over 30 years our Department is involved in investigations in spectroscopy measurements. We designed and produced several generations of multi-channel analyzers – the presented ones are the results of the best of our experience complemented with latest achievements in microelectronic technology.

We combined two different operational modes into a single unit – these are Multi-Channel Analysis and Multi-Channel Scaling. However, only one operational mode can be used at a time. Also there are two separate types of these units based on the two most popular PC interfacing techniques – PCI and USB. The PCI based unit is a 136x80 mm² board, which can be plugged into PCI slot of a Personal Computer (up to 8 of units can operate simultaneously). The USB based unit is accommodated in a screened box (110x60x30 mm³) and with a power consumption of only 140 mA. It can be powered either by the USB hub or by an external optional DC source (wall adaptor or battery). This solution eliminates the noises from the PC power supplies and other PC cards, which greatly improves the performance. The functional block diagram of USB version is presented in Figure 1.

II. ANALOG CIRCUITRY

The analog part of the circuitry is located on separate mezzanine powered by very quiet, dedicated DC/DC switching converters working at 1.2 MHz and giving ±5.2V. Individual ground planes of this mezzanine eliminate harmful noises.

A. Input Signal Conditioning and Peak Detection

The peak detect and hold circuit is a crucial element in high resolution spectroscopy. Low quality stretchers use voltage amplifiers to charge the hold capacitor through a diode. In order to provide circuit linearity the feedback loop must take up nonlinear device what introduces stability problems. This makes such a solution useless in high-speed applications. To achieve satisfactory results the storing capacitor has to be driven by a transconductance element.

In the previous version of our PCI based analyzers we used modified Buckens-Veach technique [2] for pulse stretching and peak detection. This implementation has good characteristics but is very power consuming, which is unsuitable in battery-powered applications. The novel solution of our analog stretcher is based on a diamond transconductance transistor [3]. The presented solution shifts a pole of the feedback loop deep into the safe region, meaning that edges with rise times of down to 100 ns covering the full dynamic range may be accepted and processed. The concept of the pulse stretching and peak detection is presented in Fig.2.

The circuitry is working in track or hold mode. Shottky feedback diode sufficiently reduces the after-peak pedestal, while the choice of a polypropylene storage capacitor improves performance in terms of low drop rate and of superior stability. The peak detection is achieved by monitoring the summing point of the circuitry (point A in Fig. 2).

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The point A voltage is amplified ten times to provide adequate levels for very low input amplitudes. The zero level crossings appear when the input amplitude starts to fall. The fast comparator, as shown in Fig. 3, detects this moment.

Since the input amplitude range is up to 10V and the circuitry is working with ±5.2V power voltages, the resulting levels should be appropriately compressed. The device front-end logic is shown in Fig. 4.

The analog input amplitude is monitored via a DC Restorer by the so-called Zero Level Discriminator circuitry. The DC Restorer eliminates shifts in the input level which occurs at high counting rates and voltage offsets coming from the DC coupled external preamplifiers and amplifiers. When the effective input amplitude exceeds the threshold of +10 mV, the peak detector is put into the tracking mode. The acquisition protocol is controlled entirely by the Altera FPGA.

Fig. 3 – Waveforms during peak detection. (a) is an external input amplitude, (b) is the waveform at the stretcher amplified summing node (point A in Fig. 2) and (c) is the output from the peak detection comparator.
The coupling capacitor is a 10µF multi-layer element. The incoming input analog pulses may optionally be filtered by the so-called Single Channel Analyzer (SCA). For this purpose two user-programmable 12-bit DAC’s are implemented to form a lower and an upper thresholds. In addition the SCA allows an external gating digital pulse to be applied. It can be used either in coincidence or anticoincidence mode. A valid SCA event is accepted and processing begins when the analog input pulse:

- is above the preset Lower Level Threshold,
- is below the preset Upper Level Threshold,
- satisfies selected gating settings and peak is detected.

Otherwise the event is rejected. The device may also work in the SCA mode only, which may be useful in some applications.

C. Data Digitization and Averaging

Analog-to-digital converters used in spectroscopy measurements require low differential non-linearity (DNL). Successive Approximation Register (SAR) digitizers are cheaper and have low conversion time but suffer from poor DNL (bit uniformity) so they cannot be used directly in spectroscopy applications. The introduction of the sliding scale principle [4] resolved this problem and its implementation with non-Wilkinson rundown ADC’s reduces DNL from 50% to about 1%. This averaging principle is based on statistical equalization of the ADC channel widths.

For the peak amplitude digitization we use the AD7663 a/d converter. This is a 16-bit 250 kSPS MOS charge redistribution SAR introduced recently by Analog Devices. Such a high ADC resolution allows for full scale range averaging without any additional tricks [5]. In our application the ADC works in a bipolar configuration (±5V). The positive voltage range is used for averaging while the negative range covers measured amplitudes voltage swing. Since the final result is 13 bits wide the lowest two bits are rounded (the most significant bit distinguishes voltage polarity). The implemented method causes the virtual ADC zero point to slide constantly up and down between 0 and 5V. Fig.5 demonstrates the implementation of the sliding scale linearization concept.

III. MULTI-CHANNEL SCALING

Both the USB and the PCI analyzer units provide medium speed Multi-Channel Scaling (MCS). The MCS acquisition mode is used for applications requiring a measurement of intensity vs. time, and includes interface logic to four user configurable TTL inputs/outputs for connecting a measuring instrument. The maximum counting frequency is 8 MHz. The event counting can also be based on analog signals processed by the Single Channel Analyzer. This mode of operation allows event counting up to a frequency of 1 MHz. In this case, the computer controlled SCA window makes signal filtering easy.

The Multi-Channel Scaler records the counting rate of events as a function of time. When a scan is started, the MCS begins by counting input events in the first time slot (channel 0) in the digital memory. At the end of a preset period of time, called "dwell time", the MCS advances to the next channel in the memory and continues the counting. The dwell and advance process is repeated until the MCS has scanned through the preset number of channels. A single scan through all channels is called a sweep, which may be repeated any number of times. Starting a sweep, as well as advancing from one channel to the next, may be triggered internally or externally.

IV. DATA TAKING MANAGEMENT

The entire processes of data taking as well as run time settings are controlled from the main computer with help of the TUKAN 8K program. It is possible to preset an automatic stop on exceeding the count in the programmable Region-of-Interest (ROI) as well as on expiry of the programmable real or live time. All these criteria can be imposed jointly. Live time is the time when the device in not acquiring data and the Zero Level Discriminator is off (i.e. input amplitude is below +10 mV). Overflowing any channel stops the acquisition unconditionally. Data acquisition can be suspended and restarted at any time.

The following online MCA information is constantly accessible from the device hardware: global real and live
acquisition time, counts in ROI, live time per second (3.9 ms resolution) and number of conversions per second.

Multi-channel Scaling is controlled by a 20 MHz quartz oscillator. The minimum dwell time is 2 µs while the maximum dwell time can reach over two hours. Several sweeps data can be either summed or replaced by last sweep measurement.

V. INTERFACING WITH THE HOST

The PCI interface is instantiated in the Altera FLEX chip. The self-designed PCI entity consists of a 32-bit target working at 33 MHz. It is compliant with the PCI Local Bus Specification Revision 2.2. The implementation supports the +5V as well as the +3.3V signaling. Up to 8 TUKAN-8K-PCI boards can be plugged into a single PC frame.

The USB interface is based on a FTDI FT245BM FIFO controller [6]. To achieve errorless data transfer a special communication protocol was designed. The exchange of data between the main computer (host) and the slave device (TUKAN-8K-USB) is based on messages. Transmission is always initiated by the host, which sends a numbered (modulo-16) command. Each command must be confirmed by a slave response with the same number (pipelining allowed). Well-defined frames consisting of a number of 8-bit words encapsulate the message body.

To provide efficient transmission flow control and data transparency, three unique bytes are reserved. These are SOF - start of frame, EOF - end of frame and ESM - escape sequence marker. The CRC field controls the message body.

All internal logic of both devices is embedded into the Altera FLEX 10KE30 FPGA and was fully designed using the VHDL language with the help of the QUARTUS 4.1 software.

VI. SUPPORTING SOFTWARE

The TUKAN-8K program is the result of over 10 years of experience with the previous versions of analyzers. The software has gone through many stages of upgrades and modifications according to user needs. The current version is easy to understand, very user-friendly and simple to manage. It provides:

a) full interactive data acquisition control
b) real spectrum visualization
c) spectrum and peak analysis
d) data archivization

The following functions are supported: peak, FWHM, FWTM, online background calculation; smoothing, addition and subtraction of spectra; enhanced ROI system; energy, peak-shape and efficiency calibration; Gaussian filter automatic peak search (for NaI and Ge spectrum); singlets/doublets fitting algorithms selected from a math functions library; nuclide identification; efficiency calculation.

The TUKAN-8K program works in Windows 98/ME/2000/XP environment. In Fig.6 a typical screen view is shown.

Fig. 6 - Typical screen view with accumulated spectra. The measured spectra are taken from a mixed radionuclide gamma-ray reference.

VII. RESULTS

The analog path of the devices accepts signals with rising edges down to 100 ns at full amplitude. The peak-hold mechanism has a very small pedestal of about 4 mV and a drop rate less than 300 µV/µs. The recovery from the hold mode to the tracking mode is less than 1 µs while the full conversion process takes about 5 µs. The input amplitude range is from 10 mV to 10 V. Both positive unipolar or bipolar semi-gaussian type pulses can be accepted and processed. The achieved differential non-linearity is about 0.9% while the integral non-linearity is below 0.05% over 99% of the dynamic range.

The resolution of the device is 8192 channels, software selectable in 8192, 4096, 2048 and 1024 blocks.

The MCS mode is working at a medium speed frequency of 8 MHz with a 60 ns pulse pair resolution – all MCS timing is synchronized with a precise 20 MHz quartz oscillator.

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IX. REFERENCES