REALIZATION OF A DIGITAL RATE METER AS AN IIR DIGITAL FILTER BY IMPLEMENTING AN OPTIMIZED SIGNAL PROCESSING ALGORITHM

by

Djordje ŠAPONJIĆ and Vojislav ARANDJELOVIĆ

Received on December 22, 2008; accepted in revised form on July 6, 2009

By applying the well known dualism: mean count rate – mean time between successive pulses – the equivalence between an IIR digital filter and a preset count digital rate meter has been demonstrated. By using a bank of four second order IIR filters and an optimized automated algorithm for filter selection, a practical realization of a preset count rate meter giving good tradeoff between statistical fluctuations and speed of response, particularly at low count rates such as background monitoring, is presented. The presented solution is suitable for designing portable count rate meters. The designed prototype is capable of operating up to 3600 pulses per second with an accuracy of over 4% in steady-state and responce times of 1 second for the rising edge and 2 seconds for the falling edge of the mean count rate step-change.

Key words: adaptive measurement, digital rate meter, digital signal processing

INTRODUCTION

In a recently published article [1] the authors have described a new algorithm for the measurement of the mean count rate of pulses from radiation detectors. The algorithm is based on the control of a bank of four digital IIR filters governed by the state of mean count rate – stationary or transient. The algorithm successfully solves the compromise between the contradictory requirements for low statistical fluctuations in the steady-state and a fast response to sudden changes of the mean count rate. The design of the bank of IIR filters is carried out by using the Chebyshev approximation of the second kind in order to achieve high selectivity and a high stop-band attenuation, applying as low as possible order of the constituent filters. All designed filters are of the second order. The fastest, *i. e.* the least accurate filter in the bank is on during transients, whereas the slowest, *i. e.* the most accurate filter in the bank is on at steady-states of the measured mean count rate. Two filters having intermediate characteristics are inserted between the above two filters facilitating an optimum transition between the two extreme situations. The static and dynamic characteristics of the new algorithm and the corresponding computational efficiency are tested and compared with those of the traditional rate meter algorithms.

The purpose of this article is twofold:

(1) to show that for the preset count principle of measurement there is a full equivalence between a FIR filter and the traditional moving average rate meter algorithm and also between an IIR filter and the exponential rate meter algorithm, and

(2) to present an experimental verification and describe a practical realization of the mean count rate meter carried out by applying the optimized automated IIR (AIIR) filter [1].

It has been shown that the equivalence mentioned under (1) applies to the preset time principle of measurement [2]. This article, however, deals only with the preset count principle due to its good property that, having selected a preset count, the accuracy of the measurement is constant irrespective of the level of the mean count rate.

The described realization is suitable for applications at low count rates, such as background monitoring, where the problem of finding an adequate coming,

Nuclear Technology & Radiation Protection
Scientific paper
UDC: 621.3.037.37:539.1.074
DOI: 10.2298/NTRP0902126Š

Authors' address:
Vinča Institute of Nuclear Sciences
P. O. Box 522, 11001 Belgrade, Serbia

E-mail address of the corresponding author:
avoja@vinca.rs (V. Arandjelović)

where the problem of finding an adequate compromise between contradictory requirements for low statistical fluctuations and fast response time becomes difficult. As far as the authors are aware, the described approach to designing digital rate meters has not been reported in literature. There were indications of the equivalence of FIR or IIR of the first order filters with some rate meter algorithms [3, 4], but no practical solutions appeared. An attempt to find an optimum compromise between statistical fluctuations and response time by traditional design methods [5] has shown that no significant improvements could be made by traditional methods.

THE EQUIVALENCE: DIGITAL FILTER-RATE METER

In order to implement the methods and techniques of digital signal processing (DSP) in the area of nuclear electronics, it is necessary to obtain a sequence of equidistant pulses by simple digitization of input signals. The pulses are now equidistant with amplitudes carrying information as regards time intervals between successive input random pulses from counting type radiation detectors.

The equivalence of the preset count low frequency digital filters and the traditional rate meter algorithms (moving average and exponential) will be shown by introducing the well known dualism: mean count rate (preset time principle) – mean time between successive pulses (preset count principle) [6].

For the preset time principle, the moving average algorithm is defined by

$$R(n) = \frac{1}{NT}\sum_{i=n-N+1}^{n} x(i) \tag{1}$$

and the exponential

$$R(n) = \frac{a}{T}\sum_{i=1}^{n}(1-a)^{n-i}x(i) \tag{2}$$

or in the recursive form

$$R(n) = (1-a)R(n-1) + \frac{a}{T}x(n) \tag{3}$$

where $R(n)$ is the mean count rate, N – the length of the moving average window, T – the preset time, a – the coefficient of exponential integration ($0 < a < 1$), and $x(i)$ – the number of arrived pulses witihin time T at instant i.

By applying z-transform, the expressions for the moving average and exponential algorithms become, respectively

$$\frac{R(z)}{X(z)} = \frac{1}{NT}\sum_{i=1}^{N} z^{-i} \tag{4}$$

$$\frac{R(z)}{X(z)} = \frac{a}{1-(1-a)z^{-1}} \tag{5}$$

The obtained expressions correspond to the transfer functions of the first order FIR and IIR filters, respectively. By applying the dualism between the mean count rate $R(n)$ and mean time between successive pulses $T_{av}(n)$, the following expressions are obtained

$$T_{av}(n) = \frac{1}{N}\sum_{i=n-N+1}^{n} T(i) \tag{6}$$

and for the exponential algorithm

$$T_{av}(n) = a\sum_{i=1}^{n}(1-a)^{n-i}T(i) \tag{7}$$

i. e. in the recursive form

$$T_{av}(n) = (1-a)T_{av}(n-1) + aT(n) \tag{8}$$

where T_{av} is the mean time between successive pulses, N – the length of the moving average window, *i. e.* the selected preset count, a – the coefficient of exponential integration ($0 < a < 1$) and $T(i)$ – the time interval between successive pulses at instant i.

By applying z-transform, the expressions for the moving average and exponential algorithm, respectively, are obtained

$$\frac{T_{av}(z)}{T(z)} = \frac{1}{N}\sum_{i=1}^{N} z^{-i} \tag{9}$$

$$\frac{T_{av}(z)}{T(z)} = \frac{a}{1-(1-a)z^{-1}} \tag{10}$$

The obtained expressions correspond to the transfer functions of the N^{th} order FIR and first order IIR filter structures, respectively, as obtained for the preset time principle of measurement [2]. Since the selectivity in the pass band and attenuation in the stop band of the first order IIR filters are inferior compared to those of the second order IIR filters, the AIIR algorithm design [1] was carried out by using second order IIR filters.

AUTOMATED IIR (AIIR) RATE METER ALGORITHM

The new algorithm selects the digital IIR filter from the bank of filters on the basis of the estimated gradient of the mean count rate.

The structure of the algorithm is given in the block diagram shown in fig. 1.

The structure comprises a low-pass filter, from the bank, serving for averaging the number of incoming signals, a circuit for sensing the gradient of the mean count rate, and an adaptation logic circuit, controlling the selection of the low-pass filter from the bank. Within the circuit estimating the gradient is a digital low-pass filter with parameters: pass-band limit

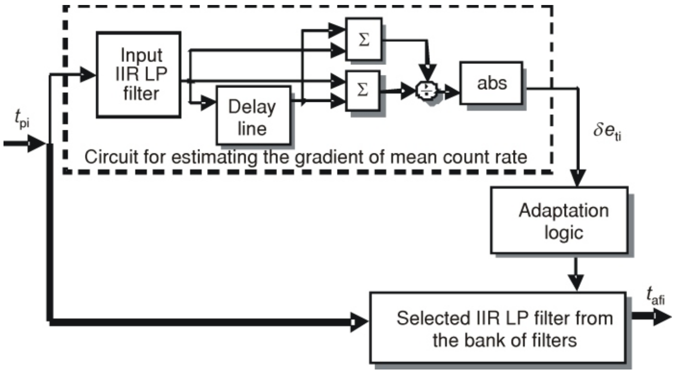

Figure 1. Block diagram of the automated IIR (AIIR) algorithm for the measurement of the mean count rate

w_p, stop-band limit w_s, pass-band attenuation a_p, and stop-band attenuation a_s chosen so as that the level of statistical fluctuations meets the minimum requirements of the international standard for health physics instrumentation [7]. This low-pass filter is followed by a structure calculating error signal δe_{ti}. A constituent part of this structure is the digital delay line D_i equal to the response time of the input digital low-pass filter. The error signal is given by

$$\delta e_{ti} \quad \frac{|t_{pi}(n) \quad t_{pi}(n \quad D_i \quad 1)|}{t_{pi}(n) \quad t_i(n \quad D_i \quad 1)} \qquad (11)$$

where

- $t_{pi}(n)$ is the averaged signal from the pulse detector (mean time between successive pulses n and $n+1$) after low frequency (LF) digital filtering, and
- $t_{pi}(n - D_i + 1)$ is the averaged signal from a pulse detector delayed by D_i (mean time between successive pulses $n - D_i$ and $n - D_i + 1$) after LF digital filtering.

The error signal δe_{ti} represents the absolute value of the normalized difference between the current and previous average value. It is input to the adaptation logic circuit, *i. e.*, it makes the basis for the selection of the LP filter from the bank. On the basis of this signal, the selection is carried out in accordance with the assigned decision thresholds. These thresholds have been introduced to speed-up transition time of the algorithm between two extreme states. The numbers of threshold levels within the adaptation logic circuit and their mutual positions have been optimized to achieve the best compromise.

PRACTICAL REALIZATION OF AN AUTOMATED IIR (AIIR) RATE METER

The practical realization of a rate meter by implementing the AIIR algorithm is carried out by using a modern microcontroller dsPIC30F4013. The basic properties of this microcontroller integrate a classic microcontroller and a digital signal processor with a hardware multiplier and Harvard architecture [8]. It is a general purpose device, supporting numerous peripherals, suitable for implementing the AIIR algorithm. The implementation relied on the use of the microPascal compiler for Microchip dsPIC microcontrollers [9] and the development system EASY dsPIC [10]. The block diagram of the developed system is shown in fig. 2a.

The input circuit consists of a radiation detector (GM tube), a high voltage supply, and a Schmitt trigger. The output pulses are fed to the external interrupt pin, INT0, of the microcontroller. Within the external interrupt routine INT0, time intervals between successive input pulses are sampled and digital processing by the AIIR algorithm is carried out. In this way the processing time is kept to a minimum, since no extra resources of the processor, which would have been required for the nesting of procedures and putting the

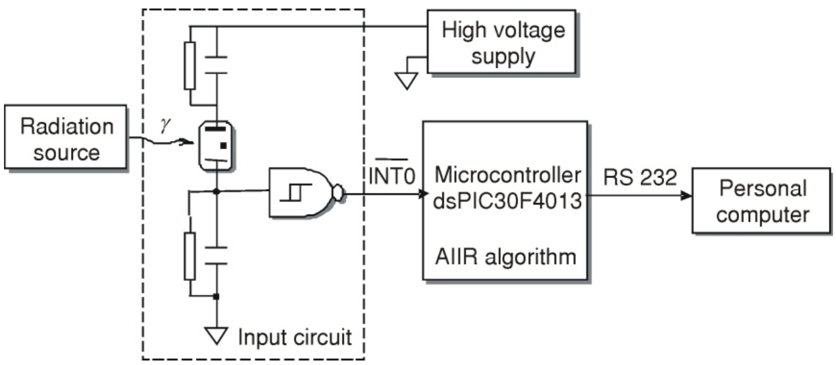

Figure 2a. Block diagram of the developed measuring system

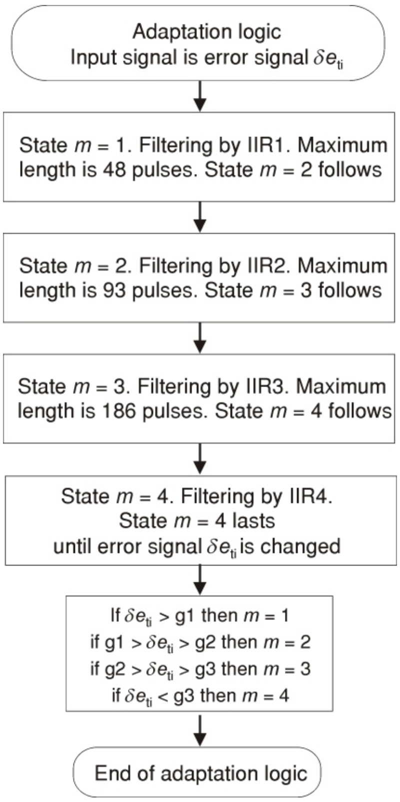

Figure 2b. Flow chart of the algorithm controlling the selection of an active filter from the bank

contents on the stack, are required. By using the 32-bit internal timer available in the dsPIC30F4013, time intervals between successive pulses are measured with a high precision (the timer clock is ¼ of the internal clock of 80 MHz, *i. e.* the resolution is 50 ns [7]). The samples are then fed to the circuit for the estimation of the gradient of the mean count rate which involves an IIR filter and a delay line (see fig. 1). In this part of the circuitry, modulo addressing and floating point arithmetic are used for achieving efficiency and accuracy, respectively.

The output of the circuit for the estimation of the gradient of the mean count rate is the error signal δe_i which is input to the adaptation logic circuit, realized as a separate procedure. The flow chart of the adaptation logic circuit is shown in fig. 2b. The procedure defines the value of the status index m which serves for selecting the corresponding filter from the bank to carry out the filtering of input signals and produce the output signal t_i. The higher the gradient of the mean count rate, the faster filter in the bank is selected and *vice versa*. Again, for reasons above mentioned, in this part of the circuitry modulo addressing and floating point arithmetic are used.

The speed of operation of the realized prototype was limited to 10 000 pulses per second by the use of a GM tube SI-10A. However, the value of the mean count rate $r_i = 1/t_i$ is given by an RS232 serial interface, each second transferred to a PC as the output of the AIIR algorithm. This method of data transfer is used since the measurement of low activities has been envisaged. These data are displayed and saved for further processing. If required, the mean count rate can also be displayed locally, by the microcontroller, on an LCD numerical display.

For most applications in environmental monitoring, the transfer rate of 1Hz is satisfactory [7]. The sampling of the AIIR output can be accelerated up to the maximum of the serial interface, *i. e.* 115200 baud. The speed of data processing by the microcontroller dsPIC30F4013 sufficiently exceeds 3600 pulses per second which corresponds to 32 bit data (floating point format) at 115200 baud of the serial interface. If a higher sampling frequency of the AIIR output is required, the USB 2.0 serial interface would be an adequate choice.

EXPERIMENTAL RESULTS

The results of practical measurements, shown in fig. 3, have been obtained by using a GM tube SI-10A and an encapsulated ^{137}Cs source.

The static characteristic, standard deviation, of the described realization has been tested by a sequence of 200000 pulses at approximately 20 pulses per second. The obtained histogram of mean count rates is shown in fig. 4. The identified standard deviation of 3.97% is in very good agreement with the designed value of 4.01%, predicted by numerical simulations applying a random number generator.

The corresponding dynamic characteristic, response time, has been tested by applying the unit step excitations from 20 pulses per second to 100 pulses per second and from 100 pulses per second back to 20 pulses per second. The rising (a) and falling (b) edges of the corresponding response of the realized measurement system are shown in fig. 5. The corresponding re-

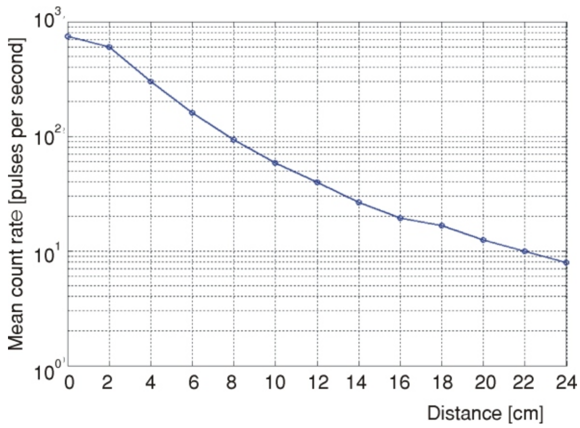

Figure 3. Level of mean count rate *vs.* distance between the source and GM detector

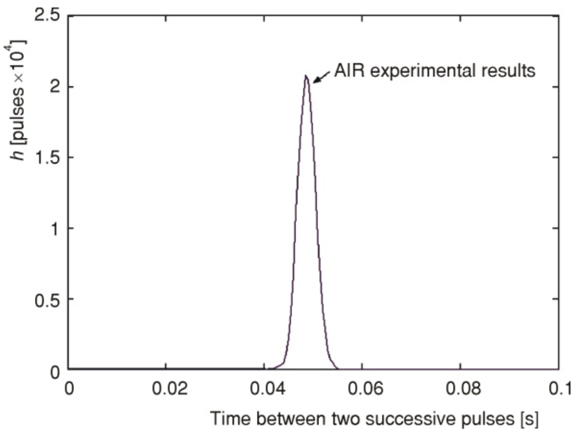

Figure 4. Histogram of the results *h* obtained by applying the AIIR algorithm at an approximate rate of 20 pulses per second

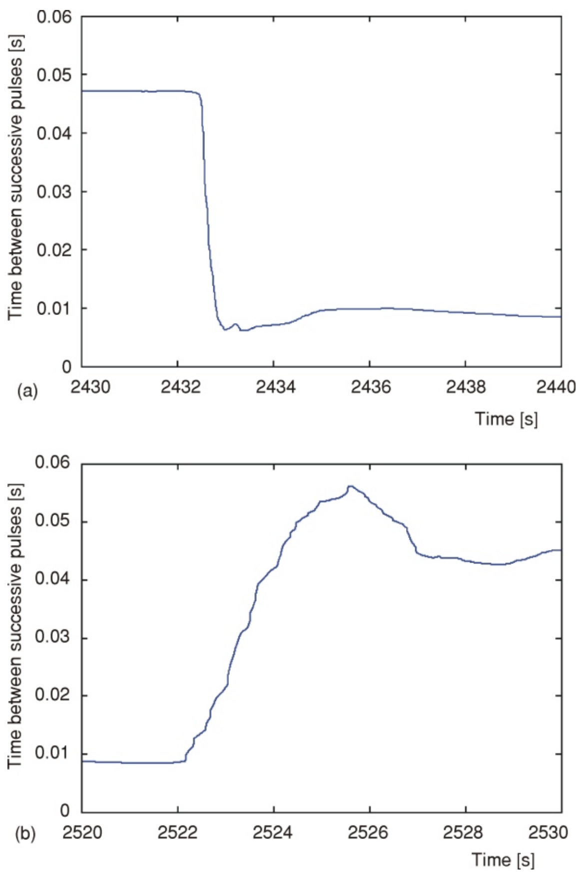

Figure 5. The rising edge (a) and falling edge (b) of the corresponding response of the realized measurement system

sponse times were 1 second for the rising edge and 2 seconds for the falling edge of the mean count rate step change, consistent with the inherent property of the preset count algorithms to respond faster to the rising edge.

The power of the presented realization is fully expressed at small count rates, when achieving a good tradeoff between the level of statistical fluctuations and speed of response becomes difficult. With or without slight modifications (such as direct display of data on an LCD display instead of using the RS232 interface), the described functional block is suitable for designing portable count rate meters applicable in environmental measurement and/or monitoring systems.

REFERENCES

[1] Šaponjić, Dj., Arandjelović, V., Stojić, M., Digital Control of a Bank of IIR Filters in Optimal Processing of Signals from Pulse Radiation Detectors, *IEEE Transactions on Nuclear Science*, *53* (2006), 6, pp. 3855-3864

[2] Milić, Lj., Koturović, A., Arandjelović, V., Algorithms of Digital Ratemeters as Digital Filters (in Serbian), *Elektrotehnika, 47* (1998), pp. E7-E14

[3] Fehlau, P. E., Comparing a Recursive Digital Filter with the Moving-Average and Sequential Probability-Ratio Detection Methods for SNM Portal Monitors, *IEEE Transactions on Nuclear Science, 40* (1993), 2, pp. 143-146

[4] Žigić, A., Preset Time Count Rate Meter Using Adaptive Digital Signal Processing, *Nuclear Technology & Radiation Protection, 20* (2005), 1, pp. 64-73

[5] Arandjelović, V., Koturović, A., The Optimum Dynamics of Preset Count Digital Rate Meter Algorithms, *Rev. Sci. Inst., 69* (1998), 12, pp. 4142-4145

[6] Knoll, G. F., Radiation Detection and Measurement, John Wiley and Sons, New York, USA, 1989

[7] ***, Radiation Protection Instrumentation – Ambient and/or Directional Dose Equivalent (Rate) Meters and/or Monitors for Beta, X, and Gamma Radiation, 2nd ed., 2002, CEI IEC 60846:2002 – 6

[8] dsPIC30F Family Reference Manual – High Performance Digital Signal Controllers, Microchip Technology Inc., Chandler, Ariz., USA, 2005

[9] ***, MicroPascal for dsPIC, Mikroelektronika Pascal Compiler for Microchip dsPIC Microcontrollers, Version 4.0.0, Mikroelektronika, Belgrade, 2005

[10] ***, EASY dsPIC, Mikroelektronika Development Tool for Microchip dsPIC Microcontrollers, Version 2.0, Mikroelektronika, Belgrade, 2006

Ђорђе ШАПОЊИЋ, Војислав АРАНЂЕЛОВИЋ

РЕАЛИЗАЦИЈА ДИГИТАЛНОГ МЕРАЧА СРЕДЊЕ БРЗИНЕ БРОЈАЊА КАО IIR ДИГИТАЛНОГ ФИЛТРА ПРИМЕНОМ ОПТИМИЗОВАНОГ АЛГОРИТМА ЗА ОБРАДУ СИГНАЛА

Применом добро познатог дуализма: средња брзина бројања – средње време између суседног импулса, демонстрирана је еквиваленција између дигиталног IIR филтра и дигиталног мерача средње брзине бројања са предодређеним одбројем. Примењујући банку од четири IIR филтра другог реда и оптимизовани алгоритам за аутоматски избор филтра, приказана је практична реализација мерача средње брзине бројања са предодређеним одбројем која даје добар компромис између статистичких флуктуација и брзине одзива, нарочито при малим брзинама бројања, као што је праћење зрачења из природе. Приказано решење је подесно за пројектовање преносних мерача средње брзине бројања. Пројектовани прототип је способан да ради у опсегу до 3600 импулса у секунди са тачношћу бољом од 4% у стационарном стању и брзином одзива 1 секунда за растућу и 2 секунде за опадајућу средњу брзину бројања.

Кључне речи: адаптивно мерење, дигитални мерач средње брзине бројања, дигитална обрада сигнала