Simultaneous multiple synchronous detection in photoacoustic measurements

Tomasz Starecki

Institute of Electronic Systems, Warsaw University of Technology
Nowowiejska 15/19, 00-665 Warsaw, Poland

Abstract. Photoacoustic detection of multiple compounds can be done in at least a few ways. One of the simplest methods is performing sequential measurements at selected wavelengths at which the compounds under detection would absorb. The main disadvantage of the method is relatively long time of the measurements – proportional to the number of wavelengths at which the measurements are performed. Time of the measurements can be significantly shortened e.g. by means of a simultaneous detection at a few light wavelengths, intensity of each modulated with a different frequency. Typical approach to implementation of such a setup requires use of a corresponding number of synchronous detectors. The paper presents a solution based on a single A/D converter and programmable logic circuit that implements high precision, simultaneous, synchronous detection of a few signals of different frequencies. The discussed equipment is capable of simultaneous recording of shape of all these signals independently. Strongly reduced hardware concept results in low cost and small size of the device.

1 Introduction

Simultaneous detection of multiple compound has many applications, e.g. ratiometric measurements of two or more compounds, detection of poisons, explosives, pollutions or even a simple chemical composition analysis of a given substance. In the case of photoacoustic measurements, one of the most common methods capable of retrieving spectral information of the investigated substance, and as a result capable of determination of its chemical composition, is FTIR PAS [1]. The method is very efficient when applied to qualitative analysis, however due to fragile mechanical and optical components, the equipment is suitable for laboratory rather than outdoor measurements. In addition, sensitivity of FTIR PAS is low in comparison to instruments which use lasers as light sources. Hence, the most common approach to photoacoustic trace detection of given compounds is based on light sources of high power density, emitting single wavelengths selected accordingly to the substance being detected. In addition, the induced photoacoustic signal is usually amplified by the acoustical resonance of the photoacoustic cell [2]. In the simplest case, measurements at consecutive wavelengths can be done sequentially, but such a solution is not very time-efficient. Time of the measurements can be shortened by simultaneous measurement at a few different wavelengths, having intensity of each modulated with a different frequency (e.g. [3]). The resultant photoacoustic signal must then be properly processed in order to evaluate amplitudes of its components corresponding to the particular wavelengths. This can be done in many ways, e.g. FFT, lock-in amplification, boxcar integration, multipoint signal averaging. The last mentioned method has the advantage of giving information not only about amplitude and phase of the signal, but also about its shape (which can be very useful e.g. if applied to pulse photoacoustics). Moreover, the sampled signal can still be processed by means of an FFT or a digital lock-in.

2 Multipoint signal averaging in photoacoustic experiments

2.1 Basic concept

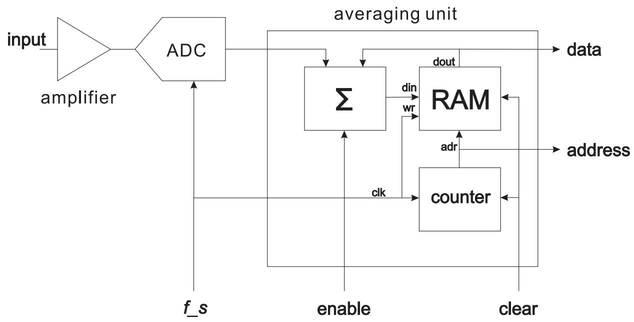

Fig. 1. A block diagram of a multipoint averaging circuit.

Multipoint signal averaging is a well known concept [e.g. 4, 5]. The block structure of such a circuit is shown in fig. 1. At the beginning of every measurement the RAM memory and the counter must be cleared (by the *clear* signal) and then acquisition of the samples can be started. The investigated signal is passed through the input stage (usually an amplifier) and applied to an A/D converter. Each conversion is triggered by a *f_s* pulse, which is simultaneously used as a write strobe that stores the previous conversion result to the RAM memory and increments the counter used for addressing the RAM memory. Frequency of the *f_s* signal must be selected in such a way that every period of the sampled signal is N times longer (where N is an integer number) than the *f_s* period, which means that N is the number of samples per period of the investigated signal. If a single period of the averaged signal is to be reconstructed, capacity of the counter must be equal to N, otherwise it should be K times greater, where K is an integer number equal to the number of periods to be reconstructed. As a result, after every overflow of the counter, the value of every new sample is added to the contents of the RAM memory which holds the sum of the corresponding samples from the previous periods of the investigated signal. When sampling of the required number of periods of the input signal is finished, the adder is disabled (by means of the *enable* signal), and the following pulses of the *f_s* signal can be used for retrieving of the averaged samples by means of the *address* and *data* lines.

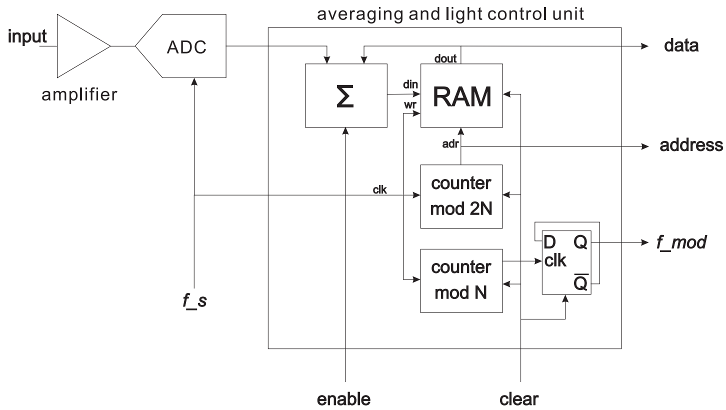

Fig. 2. A block diagram of a multipoint averaging circuit capable of producing synchronized modulation signal *f_mod*.

The main restriction in the case of the multipoint averaging implemented in the circuit from fig. 1 is selection of the *f_s* signal in such a way that number of samples per period is an integer. However, it should be noticed, that in the case of photoacoustic applications, light modulation frequency is usually in the range of hundreds of hertz to a few kilohertz, so that even sampling speed of hundreds of ksps should result in a good time resolution of the measurements (of over 100 samples per period of the input signal). Moreover, after small modification, as given at fig. 2, the circuit is capable of simultaneous multipoint averaging synchronized with generation of an *f_mod* signal, that can be used for the purpose of the light intensity modulation. The flip-flop at fig. 2 is used in order to obtain duty factor of the modulation signal equal to 50 percent.

2.2 Multichannel multipoint averaging circuit

In the above mentioned simultaneous photoacoustic detection by means of M selected wavelengths whose intensities are modulated with different frequencies, detection of the corresponding components of the photoacoustic signal can be implemented by means of M independent detectors [3]. However, such an approach results in K times higher cost and size of the detection circuit, while it should be noticed that in the case of multipoint averaging detection, the circuit from fig. 2 can be easily enhanced by additional averaging channels (as shown in fig. 3). Cost of such a solution is identical or only slightly higher in comparison to a single channel circuit, as the whole analog input block (amplifiers, attenuators, A/D converter) remains the same. The enhancement is limited to the digital block, which is usually implemented in a FPGA circuit, and in many cases change of the digital part, from the structure given in fig. 2 to the one of fig. 3 can be implemented in the same FPGA circuit.

The described concept of multichannel multipoint averaging was implemented in hardware based on an Altera Cyclone II circuit (FPGA) and Analog Devices AD 7688 converter, that can work with a resolution of 16 bits at a maximum speed of 500 ksps. The system was equipped with a 220V AC power supply and a small microprocessor system based on a microcontroller (fig. 4). The tests were performed on a two-channel multipoint averager. As the test signals, slightly modified *f_mod* signals produced in the FPGA circuit were used. The signals were applied to an external analog circuit, which was capable of independent adjustment of the signal amplitudes, filtering one of them to a sine wave and summing them together with an additional signal from a noise generator. Frequencies of the test signals were set to 1 kHz for the sine wave and approx. 990 Hz for the square wave. The amplitudes of both signals were set to approx. 1.0 V, and the noise to approx. 0.5 V (fig. 5, 6, 7). The signals recovered from such a composite by means of the implemented multichannel multipoint averager are presented on fig. 8. It should be noticed that in the case of fig. 4, the time of averaging was only 0.1s, but both detected signals were of similar amplitude and were greater than noise, so that even such a short averaging time resulted in efficient cancelling of noise and disturbing signals. During later tests, the amplitude of the sine wave was significantly reduced below the noise floor, but even in such a case the averaging gave very good results (see fig. 9), although the required averaging time was much longer.

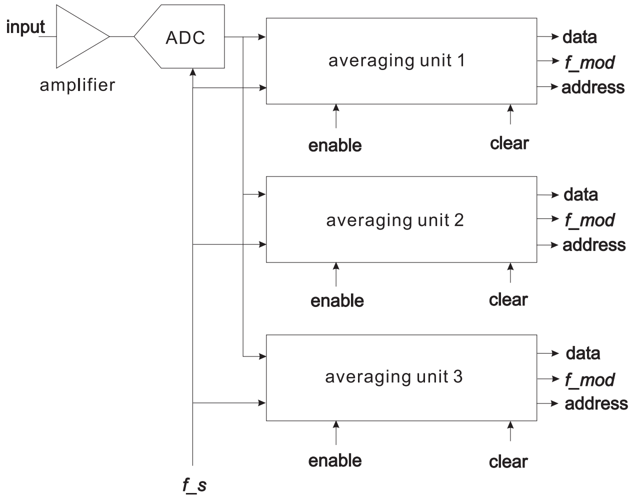

Fig. 3. A block diagram of a multichannel multipoint averager.

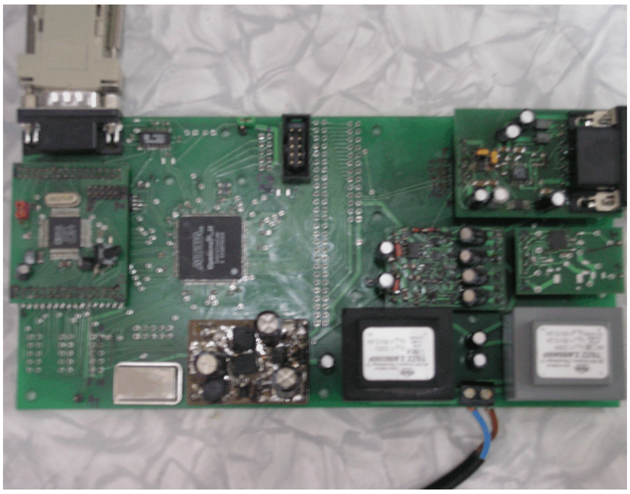

Fig. 4. Implemented hardware of the multichannel multipoint averaging circuit.

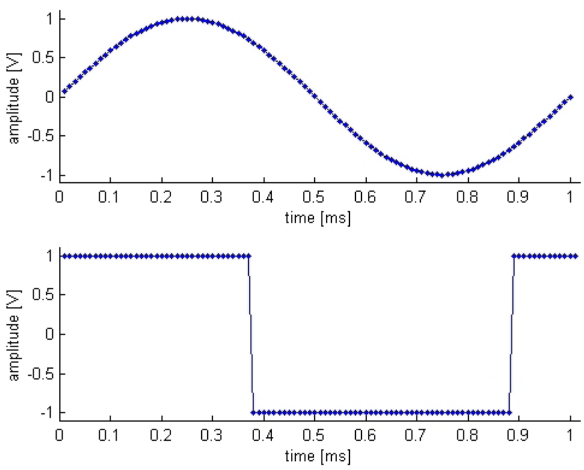

Fig. 5. Signals used for the purpose of testing of the implemented averaging circuit.

3 Conclusions and remarks

Preliminary test results of the presented concept of multichannel multipoint signal averaging showed that the method can be efficiently implemented in simultaneous photoacoustic detection of multiple compounds. It looks as though the method can be also used in other (not necessarily photoacoustic) applications, which require a few components of different frequencies of a common signal to be detected synchronously at the same time. An important advantage of the presented solution is that the circuit can also produce corresponding modulation signals. Due to implementation of the digital part of the instrument in a single FPGA circuit, cost, size and power consumption of the multichannel multipoint signal averager were significantly reduced.

References

1. M.M. Farrow, R.K. Burnham, E.M. Eyring, Appl. Phys. Lett. **33** (8), 735 (1978)
2. Z. Bozóki, J. Sneider, Z. Gingl, Á. Mohácsi, M. Szakáll, Z. Bor, G. Szabó, Meas. Sci. Techol. **10**, 999 (1999)
3. J.-P. Besson, S. Shilt, L. Thévanaz, Spectrochim. Acta A **63**, 899 (2006)
4. J. Parisi, B. Mühlemeier, W. Buck, Rev. Sci. Instrum **57** (6), 1196 (1986)
5. A. Black, R. B. Apte, D. M. Bloom, Rev. Sci. Instrum **63** (5), 3191 (1992)

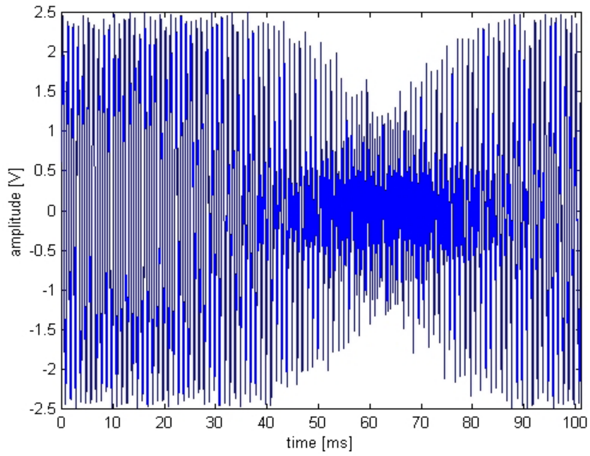

Fig. 6. Composite test signal containing both signals from fig. 5 and noise.

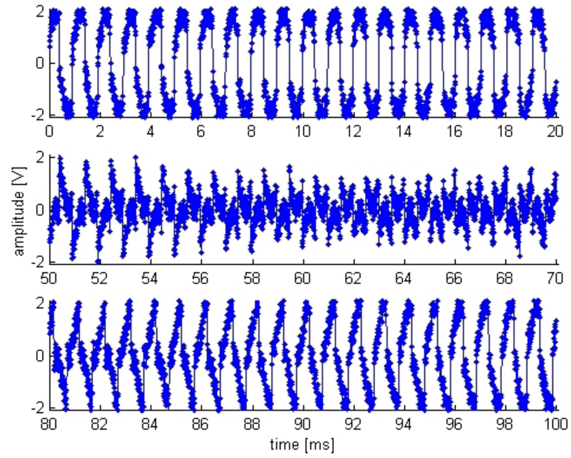

Fig. 7. Zoom of a few selected periods of the signal from fig. 6.

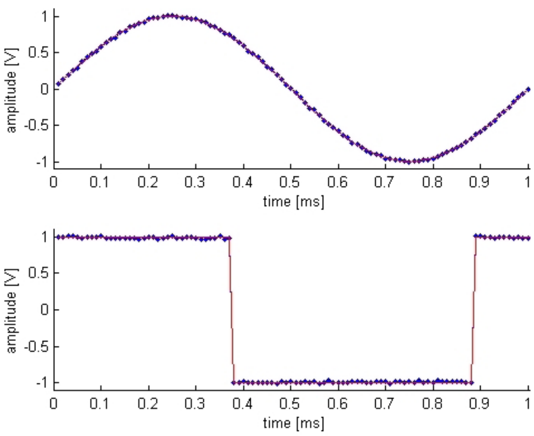

Fig. 8. Example of the recovered signals ($t_{AVR} = 0.1$s).

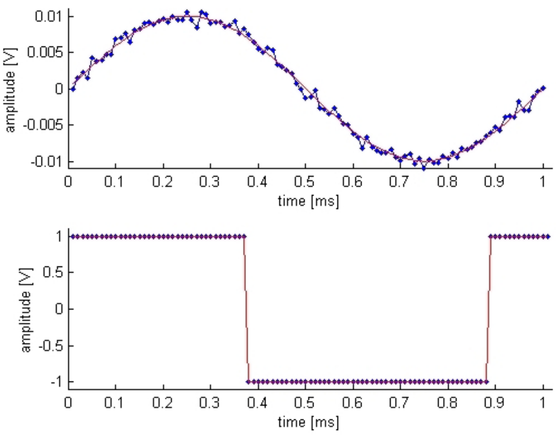

Fig. 9. Example of the recovered signals ($t_{AVR} = 200$s).