IMPLEMENTATION OF REAL-TIME AND STROBOSCOPE SAMPLING OF PHOTOACOUSTIC SIGNAL BASED ON CPLD CIRCUITS

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Abstract: The paper presents implementation of the main digital block of a photoacoustic measurement and control system in which signal processing is performed mainly in digital form. The device produces light source modulation signal and A/D converter control signals. Modulation frequency and number of samples per period of the recorded signal are programmable. The signal acquisition can be performed in real-time sampling or stroboscope sampling mode.

Keywords: data acquisition, sampling control, microcoprocessor control, digital control, sampling rate

1. INTRODUCTION

Despite from constant rapid progress in the field of technology, most of practical implementations of photoacoustic equipment are based on traditional analogue signal processing (boxcar integrators, etc.) and are sophisticated, large and expensive systems (Julliard, *et al.*, 1997; Kapitanov, *et al.*, 2001; Schramm, *et al.*, 2003). As if we speak about the equipment used for research in the field of photoacoustics, it is usually required that multiple measurement factors can be changed independently, so that it is possible to evaluate their influence on measurements and find optimal measurement conditions. Such a versatility of the experimental photoacoustic setups leads usually to the mentioned big, complex and expensive designs. Even modern designs of experimental photoacoustic setups, which are based on microcontrollers and modern technology, are still far away from optimal use of electronics and digital signal processing (Firebaugh, *et al.*, 2002; Santiago, *et al.*, 2003; Song, *et al.*, 2002). The paper presents some preliminary results from a project aimed to develop a low-cost, small-size device that would preserve most of properties of the mentioned sophisticated systems.

2. INITIAL CONSIDERATIONS

As nowadays semiconductor lasers and LED diodes are more commonly used as light sources (Bozóki, *et al.*, 2002; Bozóki, *et al.*, 2003; Boschetti, *et al.*, 2002; Fischer and Sigrist, 2002; Starecki 1993) it was assumed that the output light source modulation signal will be produced as an electric signal: 50 percent duty cycle square wave (TTL/CMOS compatible) with the frequency tunable in the range of 20 Hz – 20 kHz. Such a solution requires a small external driver circuit, but reduces the restrictions on the light modulation method, that can be implemented not only as a semi-conductor laser or LED current modulation, but also by means of acoustooptical or electrooptical modulators.

It was also assumed that in some experiments not just amplitude and / or phase, but the whole signal shape may be of interest, so the device must be capable of recording the signal with the resolution (software programmable) in the range of at least a few tens to a few hundreds of samples per period. Vertical resolution (amplitude measurements) of 12 bits seemed to be satisfactory, but again it was assumed that the design must allow easy upgrades to higher resolution and / or faster A/D converters.

A block diagram of the device is presented in Fig. 1. The analog part of the device consists of blocks in which the photoacoustic signal is amplified and converted to digital samples. Due to low level of photoacoustic input signals and significant level of noise produced by fast digital circuits, the digital part of the device was separated from the analog part by means of optocouplers. Similar approach was used for isolation from the light source modulation circuit, because strong current pulses (e.g. if a semiconductor laser is used as the light source) may produce noise that would disturb operation of the other circuits. Due to

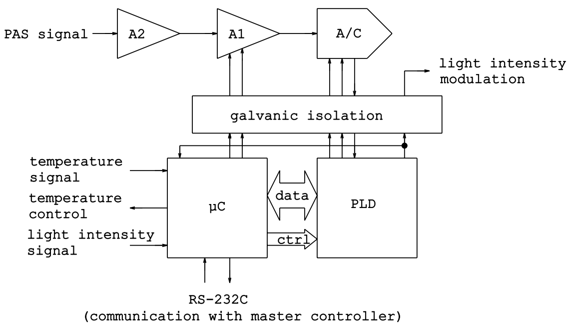

Fig. 1. Block diagram of the system.

optoisolation, the A/D converter used in the analog part has serial data output.

Because of relatively fast signals that are needed to control the A/D converter and relatively high requirements to the time resolution of digital control signals, some of the digital part functions were implemented in a PLD circuit. Its role was to produce a light beam modulation signal and (appropriately synchronized with it) signals used for controlling the A/D converter.

For testing purposes MAX 176 was used in the system as the A/D converter, although there is number of faster and higher resolution A/D converters available on the market, which can be used instead. However it should be noticed, that there is no point in choosing much faster one. If one does so, e.g. in order to obtain real-time sampling of a 20 kHz signal with the resolution of 100 samples a period, the converter should have maximum sampling speed of at least 2 Msps (in comparison to 250 ksps of MAX 176). And due to the serial output of the converter, the mentioned 2 Msps would result in the serial data transfer speed of approximately 30 Mbauds, so that simple optocouplers may be not fast enough and isolation would have to be implemented in a more sophisticated way (e.g. as magnetic coupling). Another thing is that real-time data acquisition with the speed of 2 Msps would require much faster microcontroller or a DSP processor. Hence, use of a much faster (means also more expensive) A/D converter would result in significant increase of the device costs and may require the whole system to be redesigned. At the same time it should be mentioned, that similar result (i.e. sampling of a 20 kHz signal with the resolution of 100 samples a period) can be obtained even in case of much slower converters, if a stroboscope sampling technique is applied. The main disadvantage of the stroboscope sampling is longer data acquisition of the input signal, but it should be noticed that the technique is used only at relatively high input signal frequencies, while as long as the speed of the converter is sufficient, real-time sampling is implemented. For MAX 176, assumed 100 samples a period and real-time sampling, the maximum input signal frequency is 2.5 kHz, which is still satisfactory for probably most of photoacoustic applications.

3. DATA ACQUISITION AND CONTROL

Sampling method implemented in the designed device slightly differs from standard techniques used in digital oscilloscopes or digital signal recorders. There are three sampling techniques used in oscilloscopes and recorders: real-time, stroboscope, and random sampling. Random sampling is not discussed here, because lack of synchronization between the signal and sampling strobes makes the technique unuseful if corresponding samples of the consecutive periods of the signal are to be averaged. In the two other techniques (real-time, and stroboscope), time axis position of a sample is referred to a trigger signal position. The instrument must be then equipped in a trigger circuit and a time-base circuit. Time-base length in scopes and recorders is not synchronized with the period of the sampled signal – number of samples in a given number of periods of the measured signal is usually not an integer value. This can be a disadvantage in case of some digital signal processing operations (e.g. filtering).

In photoacoustic instruments the signal used for light source modulation can be also used as the time reference. Taking into consideration that the designed device should produce light source modulation signal as well as A/D converter control signals, all of them can be generated as already properly correlated. From the point of view of digital signal processing the best situation is when an integer number of periods of the measured signal are sampled. Hence it was assumed that during every single period of the light source modulation signal an integer number of N samples of the photoacoustic signal would be taken. In case of real-time sampling (i.e. when N and light source modulation frequency f_{mod} are of moderate values), the sampling frequency f_s will be:

$$f_s = f_{mod} * N \tag{1}$$

Such f_s and f_{mod} signals can be produced in a very simple digital circuit (Fig. 2), in which the f_{osc} frequency can be generated in a crystal oscillator, while the programmable modulo-K counter is used for concurrent adjustment of f_s and f_{mod} frequencies. In order to obtain

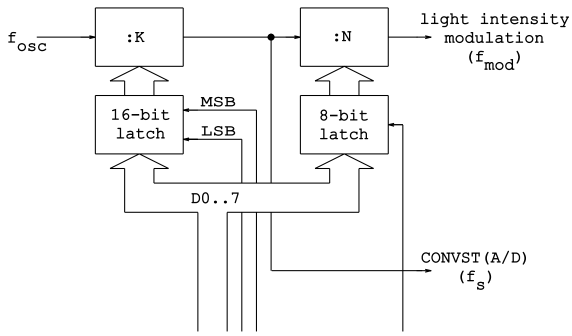

Fig. 2. Block structure of a simple circuit producing synchronized f_{mod} and f_s signals.

smooth tuning, the value of f_{osc} should be much higher than f_s. As for MAX 176 the maximum sampling speed f_{s_max} is 250 ksps, a relatively smooth tuning should be obtained if the value of f_{osc} is greater or equal 25 MHz.

When the value of f_{mod} and / or N is increased it may happen that the $f_{mod} * N$ product is greater than the maximum sampling speed of the A/D converter (f_{s_max}), so that real-time sampling is not possible. In such a case stroboscope sampling technique can be used, so that in every period of the measured signal only every M-th out of N samples is taken. As a result, the time-slot between consecutive samples, as well as the time required for a measurement, are M times longer (in comparison to the real-time sampling). A simple modification of the circuit from Fig. 2, which supports both, real-time and stroboscope method of data acquisition is shown in Fig. 3. It should be mentioned, however, that for the correct operation of the circuit, M and N values must be relatively prime numbers. Otherwise, if the distance between every two consecutive samples is identical, some of the samples will never be collected. This can be easily seen from an example; e.g. when $N = 4$ and $M = 2$ in every period of the measured signal only 2-nd and 4-th sample will be taken, while 1-st and 3-rd sample will never be taken.

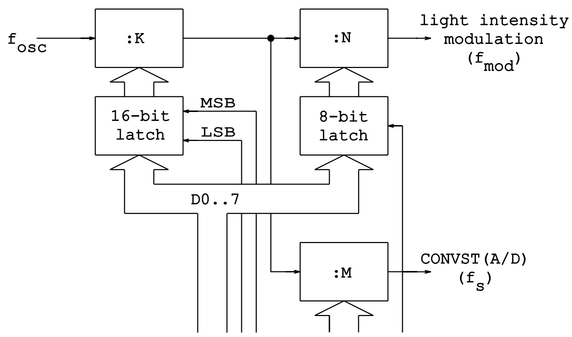

Fig. 3. Modified circuit from Fig. 2, supporting real-time and stroboscope sampling.

4. DIGITAL BOARD

A detailed circuit diagram of the digital board is presented in Fig. 4. The A/D converter control signals are produced in a programmable logic circuit U51 (ispLSI 1032, Lattice Semiconductor) and, together with the A1 stage gain selection signals, are routed to CON55 connector (which is connected by means of a flatcable with the analog board). The U51 generates also a light source modulation signal, which is separated from the main (external) light source modulation circuit by means of U53 optocoupler. The signal is also connected to an external interrupt input of U54 microcontroller, so that it can be used e.g. as a time position reference of the collected photoacoustic signal samples to the light modulation signal. The CON57 connector is used for in-system programming of the AT90S8535 microcontroller (Atmel). It is an 8-bit RISC with computation power of a few MIPS and internal memory resources sufficient for 250 ksps data acquisition and real-time implementation of some basic operations, like averaging.

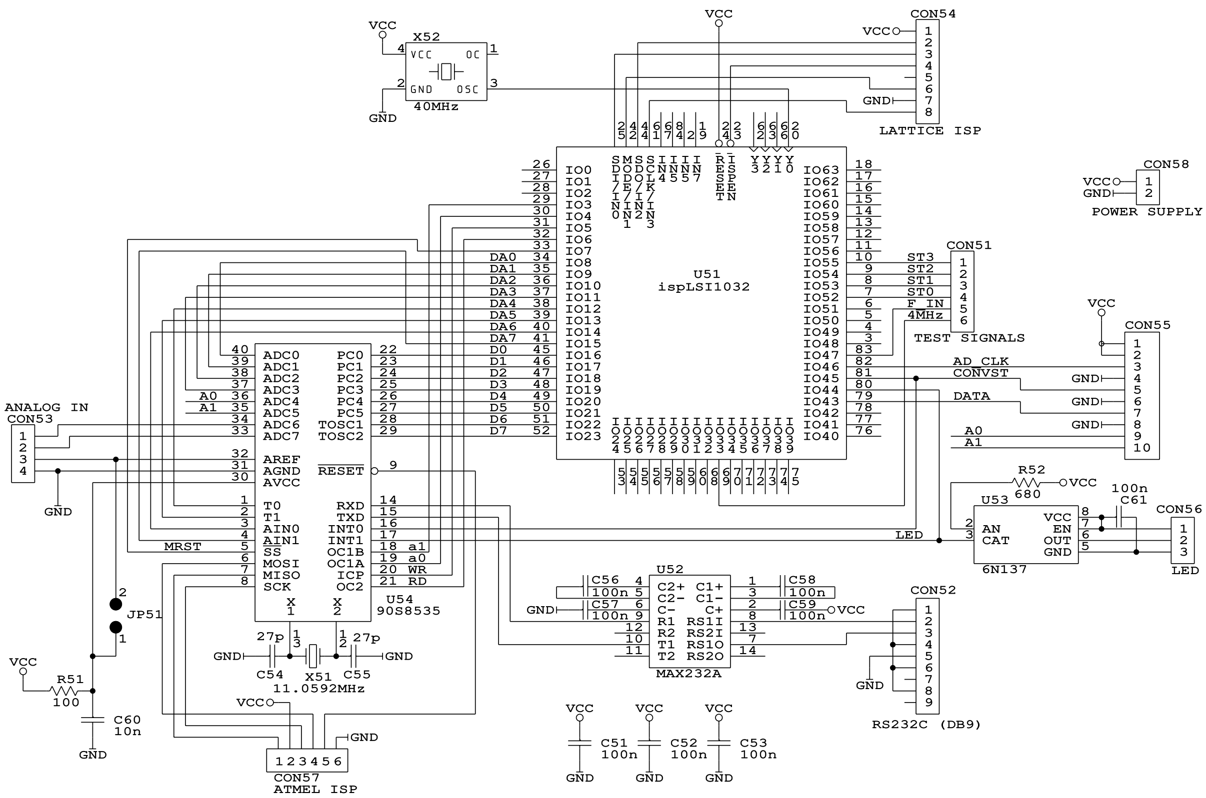

Fig. 4. Digital board circuit diagram.

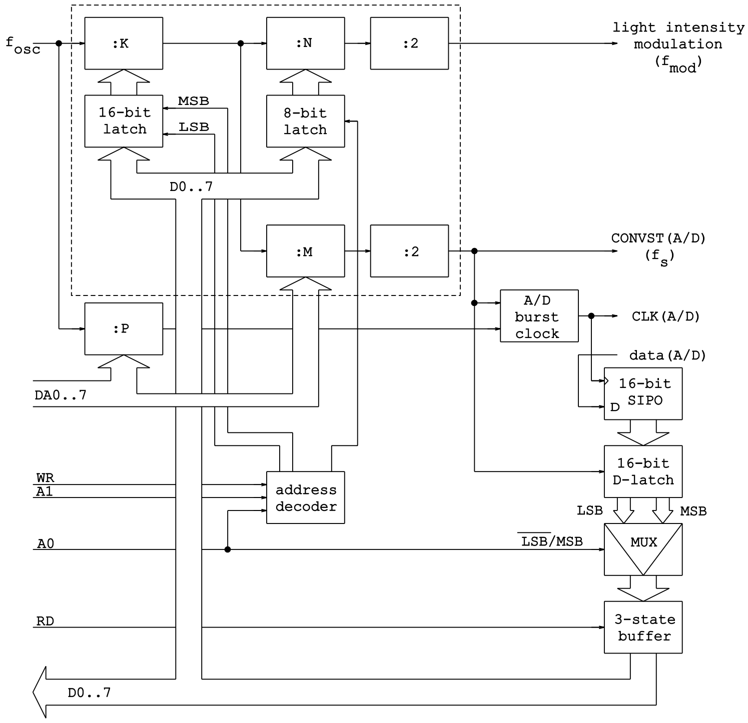

Fig. 5. Functional structure implemented inside ispLSI 1032.

Communication between the device and external master device (e.g. a computer) is based on RS-232 interface. MAX232A (U52), used as TTL/CMOS <=> RS-232 level converter, supports baudrates up to 120 kbps, so that a standard baudrate of 115.2 kbps can be used. Such a transfer speed is sufficient if taken into account that 12-bit sampling (at maximum MAX 176 conversion speed) with a resolution of 100 samples a period and averaging of 2500 periods will take approximately one second, while transferring the results of such a measurement (300 bytes) will last only 26 ms.

5. FUNCTIONAL STRUCTURE IMPLEMENTED IN THE PROGRAMMABLE LOGIC

A functional structure implemented in the PLD circuit is presented in Fig. 5. The circuit generates light source modulation signal and, synchronized with it, A/D converter control signals. Some properties of these signals can be set by the microcontroller via a parallel microprocessor interface that was also implemented in the PLD. The interface is also used for reading out the data received from the A/D converter.

The part of the structure framed by a dashed line is very similar to the structure shown in Fig. 3. It should be noticed, however, that the circuit shown in Fig. 3 is not capable of producing 50% duty cycle f_{mod} signal if N is an odd number. That is why the circuit from Fig. 3 was modified by adding a flip-flop (which divides the frequency by two, producing a 50% duty cycle square wave) at the output of modulo-N counter. In order to keep the ratio of the f_{mod} and CONVST signal frequencies unchanged, similar flip-flop was added at the CONVST output. Additional result of adding the flip-flops is extension of the CONVST pulses, which is quite important as the signal is also used by the microcontroller as an A/D data ready signal. Extension of the CONVST pulses does not affect operation of the converter, because conversions are triggered by the edge, not level, of the CONVST signal (Maxim / Dallas, 2002). The converter clock signal (Fig. 6) is produced in an A/D Burst Clock circuit which (in response to active edges of the CONVST signal) generates bursts of fourteen 125 ns (fitted to the maximum speed of MAX 176) pulses out of a regular 4 MHz clock which is taken from a modulo-P 4-bit counter (the PLD clock was set to 40 MHz, hence $P = 10$). Consecutive data bits output by the converter in response to the burst pulses are shifted into a SIPO (serial in parallel out) register which contents is latched to an additional parallel register by the active edge of the CONVST signal, so that result of the previous conversion is stable and can be easily read out by the microcontroller while another conversion is in progress.

Virtually all of the counters implemented in the ispLSI 1032 are programmable counters. In case of modulo-K and modulo-N counters, division ratio values are stored in latches implemented internally in the PLD. However, the ispLSI 1032 has not enough register resources

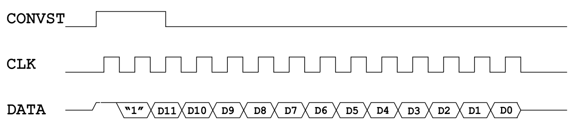

Fig. 6. MAX 176 conversion timing (Maxim/Dallas, 2002).

to implement internally similar registers that would store division ratio values for modulo-P and modulo-M counters. Therefore these registers are implemented externally to the PLD, in the microcontroller. Their outputs, present at the microcontroller pins, are connected (by means of the DA0..7 bus) to the PLD pins, and then internally to appropriate counters.

8. APPLICATION EXAMPLE

The designed device was tested in an experimental setup used for calibration of photoacoustic cells. The system was controlled by a simple application written in Borland Delphi environment, run on a PC computer. A screenshot example of the user interface of the application is shown in Fig. 7. The user can set the gain of the analog signal path, number of samples a period, number of periods to be averaged, can fix modulation frequency at a selected value or define a frequency range and sweeping step, etc. Two graphic windows present amplitude vs. frequency characteristics and shape of the measured signal. In addition some information, e.g. DC offset, amplitude and phase values are presented to the user in a digital form. The measurement results can be saved in a file.

9. CONCLUSIONS

A result of the described work is a system for data acquisition and control dedicated for photoacoustic measurements. Implementation based in great part on programmable logic and digital signal processing resulted in substantial reduce of the system cost (below 100$), small size, and very high functional flexibility. As most of the measurement settings are programmable and can be changed at run-time, the system is very well fitted for research and development in the field of photoacoustics. Implementation of real-time and stroboscope PAS signal sampling makes possible to acquire high resolution samples while preserving wide input bandwidth. Due to in-circuit programmable components, upgrades of the device are very easy. Small size and low power consumption make the device a very good choice for implementation of portable photoacoustic instruments.

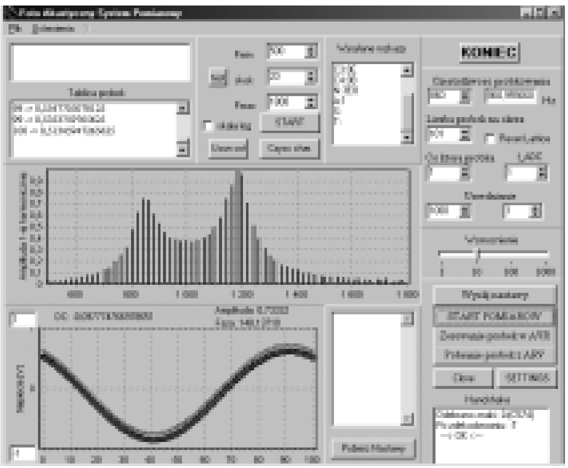

Fig. 7. A screenshot of the software used in calibration of photoacoustic cells.

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