Concept of virtual instruments applied in photoacoustic measurements

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A method is presented by which photoacoustic measurements can be done fast and with small effort. All operations are performed by an automatic measurement system based on an IBM PC personal computer. The structure and principles of the system operation are presented. The main advantages of the method described are: short time of measurement, wide chopping frequency range, high accuracy, and low error level. Owing to the computer some operations like hardware averaging, filtering, etc. can be replaced by software. This results in simplicity of the setup.

If we need to perform a large number of measurements with a high accuracy, the best solution is to use an automatic measurement system. In recent years some photoacoustic experiments carried out by means of such systems have been reported.[1–5] However, in all of that solutions the changes of the setup structure in comparison to traditional experimental arrangement are rather small. The main parts of the setup, e.g., chopper and the lock-in amplifier, are used in the same way as in traditional arrangements and only some interfaces to the computer are added. The solution presented here is an automatic measurement system based on the concept of virtual instruments,[6] that is, such a system in which hardware is replaced by software as much as possible.

In most experimental arrangements laser or high-power arc lamp is used as a source of radiation.[7–10] Modulation of the emitted light can be obtained by means of an electro-optic or acousto-optic modulator, although the mechanical chopper is still the most popular choice.[7–10] Application of a light-emitting diode (LED) as a source of modulated light has also been reported.[11] The main drawback of the last solution is the small output light power. However, the LED is small, cheap, and its light intensity can be easily modulated with a frequency of 0 Hz–1 MHz. Moreover, modulating signal can be of any shape (square, sine, triangle, etc.) and the stability of the light modulation frequency is equal to the stability of the modulating signal frequency. Besides, in some applications commercial IR LEDs working in the 0.78–1.0 μm range can be used. Output light power that can be obtained from such IR LEDs has a typical value of 1–100 mW. In this work a LD271 (Litronix) diode was used. LD271 is a commercial IR LED which can emit up to 16 mW of an average light power at the wavelength of 0.95 μm. The diode was controlled by a waveform generator card buffered with a simple current driver (Fig. 1).

Pressure changes in the photoacoustic cell used in this work were detected by an electret microphone TONSIL-MEO 55. Signal from the microphone was increased by the gain of about 10^4 in a simple band-pass amplifier built of two op-amps (NE5534A, LM318). In this way the level of the signal was matched to the input voltage level of a waveform recorder card. The card used in the experiments had an 8-bit resolution and a 10 MHz maximum sampling rate. The signal was recorded with the resolution of 100 points a period, hence it was possible to record the signals with a repetition rate of up to 100 kHz. Such high frequencies are much above the upper bandwidth limit of the microphone, but can be useful if a piezoelectric detector is used.[12,13] Recording of a full waveform not only of its amplitude and/or phase gives more information about the effects which occur in the chamber. Hence applying a waveform recorder instead of a lock-in detector should improve the metrological properties of the system. The small voltage resolution of the recorder can be a disadvantage, but can be easily compensated by means of an amplifier with a digital gain control.

The system was tested by means of a simple program for photoacoustic cell measurements. The ratio of the modulation frequency and sampling rate set by the software is always constant and equals 1:100, which makes each period of the signal to consist of 100 samples. Constant ratio of the frequencies simplifies subsequent signal processing because all the parameters of digital filtering, averaging, etc., are constant and independent of the frequency. The waveform recorder is triggered by the waveform generator (Fig. 1) in order to obtain full synchronization between the modulating and recorded signals. Values of the ampli-

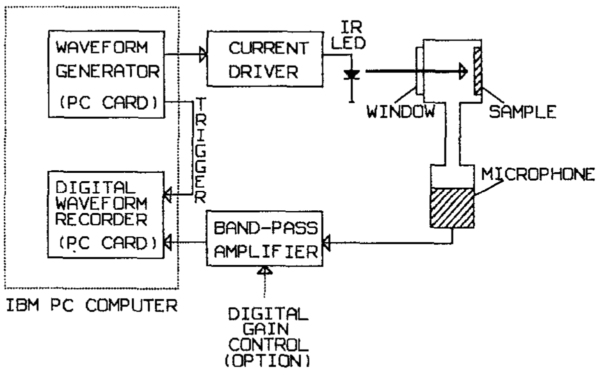

FIG. 1. Block diagram of an experimental arrangement for photoacoustic measurements. Structure of the system is based on concept of virtual instruments.

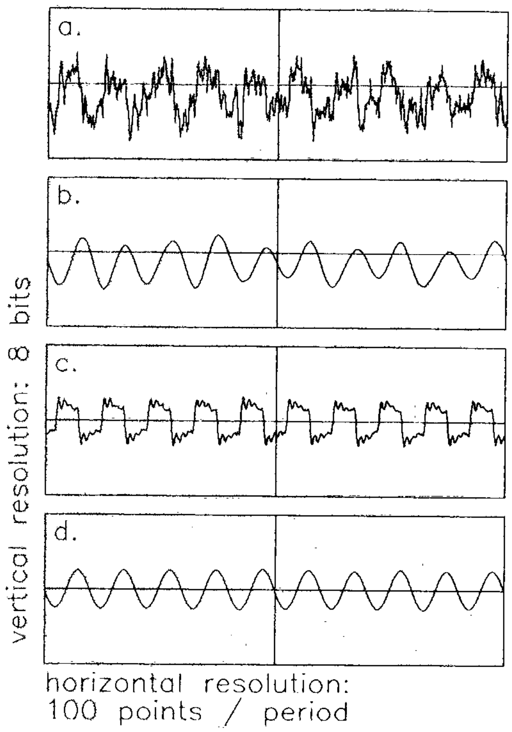

FIG. 2. Comparison of a typical photoacoustic response before and after digital signal processing. (a) Single trace of the recorded signal. (b) Strong noise reduction as a result of filtering. (c) Original shape of the signal obtained by averaging of 100 traces. (d) Nearly pure sine wave observed after filtering of the averaged signal.

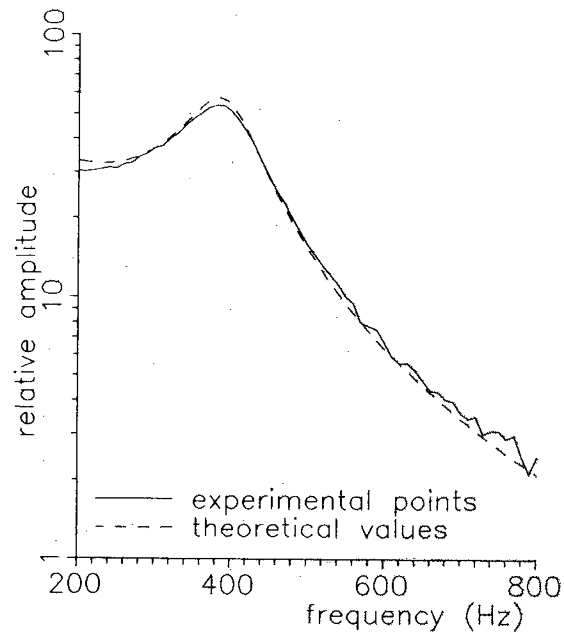

FIG. 3. Photoacoustic signal amplitude vs modulation frequency.

tude and phase of the signal are determined by the least-squares method.

A typical photoacoustic response recorded in the system is shown in Fig. 2(a). The SNR of the observed signal is not very high but can be significantly increased by passing the signal through a three-pole low-pass digital elliptic filter [Fig. 2(b)]. However, this method eliminates all the harmonics of the signal. The original shape of the microphone response can be reproduced by signal averaging [Fig. 2(c)]. Averaged signal that passed through the mentioned filter gives nearly pure sine wave [Fig. 2(d)]. It should be noticed that filtering changes the signal phase. However, the value of the phase deviation is known and constant, hence it can be easily corrected in final calculations.

The system presented in this paper was used for determination of resonance curves of a Helmholtz resonator. The resonance curve obtained in the measurements is presented in Fig. 3. The amplitude of the recorded signal is related to the value of the least significant bit of the waveform recorder. As can be seen, the experimental values (solid line) are close to the theoretical ones (dashed line) obtained from the calculations of the extended Helmholtz resonator model.[14–16] Noise reduction due to signal averaging and very good properties of the least-squares method lead to good agreement between the theoretical and experimental values even in the range of small amplitudes.

The concept of virtual instruments applied in photoacoustic experiments gives promising results. The size and cost of equipment are considerably reduced. Additional functions, e.g., temperature control, light-power determination can be easily implemented. Due to the high upper limit of the frequency modulation both microphone and piezoelectric detectors can be used.

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