Influence of the light intensity on the operation of the self-oscillation photoacoustic setup

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Abstract. In the traditional approach to photoacoustic measurements, the light source modulation frequency is fixed, or a resonance tracking mechanism is applied, that adjusts the modulation frequency to the instantaneous value of the resonance frequency of the cell, especially in the case of high Q-factor cells. However, photoacoustic measurements can also be based on a novel method in which the light intensity is modulated by the photoacoustic signal induced in the cell, hence forming a photoacoustic oscillator. Frequency of such an oscillator and shape of the resulting photoacoustic signal depend mainly on the resonance properties of the cell, but also on the power of the light irradiating the investigated sample. This paper describes the influence of the intensity of light used for exciting the photoacoustic signal on the operation of such a photoacoustic generator.

1 Introduction

A standard approach to photoacoustic experiments is modulation of the light source intensity with a fixed frequency. It is also possible to implement a photoacoustic setup that would self-tune to the optimal modulation frequency determined by the resonance frequency of the cell [1]. As a result, amplification of the photoacoustic signal by the acoustic resonance of the cell can be maximized. Such a setup can be treated as a photoacoustic generator. Application of such a solution can be of great advantage, especially in the case of high-Q cells ($Q > 1000$), that in traditional applications require additional resonance frequency tracking mechanisms to be implemented, so that the modulation frequency of the light intensity is continuously adjusted to the resonance frequency of the cell. Such solutions are required, as in the case of high-Q cells the resonance peak is very narrow and the resonance frequency is affected by many factors - in particular by the temperature, which strongly influences sound velocity of the gas filling the cell, resulting in dramatic decrease of the photoacoustic signal due to shifting out of the cell resonance if the temperature is changed even by a fraction of a degree [2].

2 Theory of operation of a photoacoustic generator

According to the theory of operation of electronic sine wave generators, in order to obtain a circuit working as a generator it is necessary to use an amplifier (with a gain K) and a feedback network (with a transmittance β), with the additional requirement of so-called amplitude and phase conditions, which state that at the resonance frequency:

$$|K\beta| = 1, \quad \varphi(K\beta) = 2\pi N, \tag{1}$$

where N is an integer number [3]. Such conditions mean that the amplifier gain must at least compensate losses introduced by the feedback network, the circuit must work with a positive feedback and that oscillation frequency is set to a value at which the phase shift of the amplifier is compensated by the phase shift of the feedback network. Such conditions can be fulfilled in a photoacoustic generator from fig. 1 if the gain and phase shift of the amplifying stages are properly set. It should be noticed, that in the mentioned circuit the feed-back network is defined by the transmittance of the photoacoustic circuit, which depends (among others) on the frequency response of the photoacoustic cell.

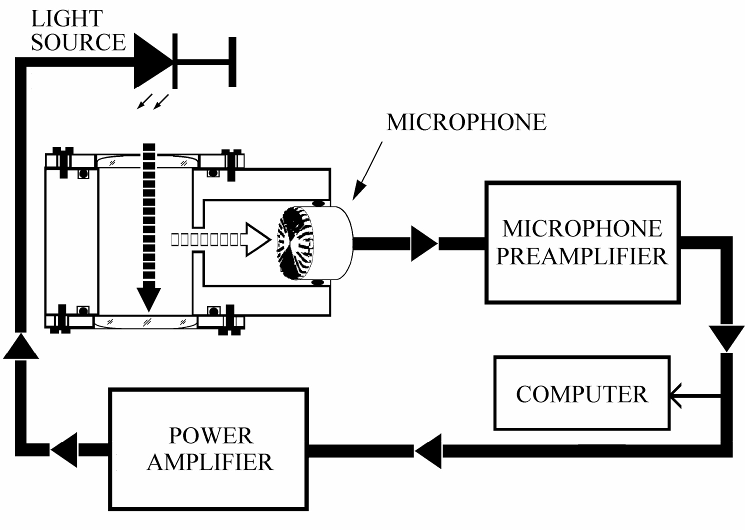

Fig. 1. Block structure of a photoacoustic generator.

3 Experimental results

It should be noticed that in the case of electronic generators, the frequency of oscillations is affected by many factors, e.g. supply voltage, temperature, module of the $K\beta$. It can be expected that for a photoacoustic generator, the output signal will be influenced by temperature, chemical composition of the investigated sample (affecting amplitude and phase shift of the photoacoustic signal), intensity of light irradiating the sample, etc. In order to evaluate the latter a simple photoacoustic setup was build. The setup consisted of an IR LED (HDSL 4220 – 875 nm, 38 mW/sr) controlled by a saturated switch

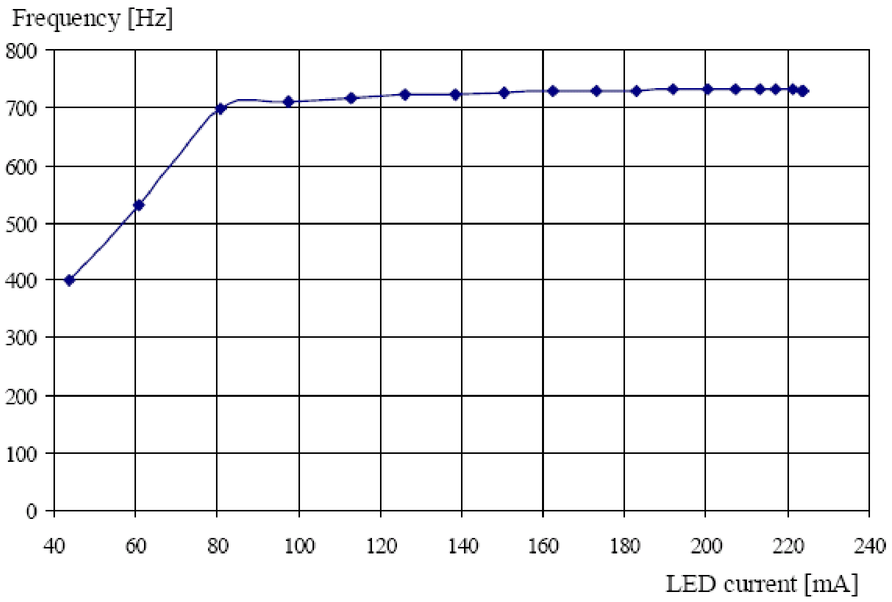

Fig. 2. Influence of the light intensity on the oscillation frequency of the photoacoustic generator.

circuit, that simplified adjustments and measurements of the average current flowing through the LED, and as a result the light power (the mentioned LED displays a perfect linearity of the light intensity vs. forward current). Photoacoustic signal was detected by means of a low-cost electret microphone (sensitivity of approx. 1mV/Pa), amplified by a factor of 1000 and then used for controlling the mentioned saturated switch. A cell used in the experiment had a resonance frequency of about 760 Hz and it was intentionally selected as a Helmholtz resonator of relatively low Q-factor (Q of about 3), in order to obtain strong dependence of the oscillation frequency on the light intensity. In the case of a high-Q cell, resonance frequency changes would be of a fraction of a hertz, moreover, a perfect thermal stabilization of the cell would be required in order to minimize influence of the temperature on the resonance frequency of the cell.

Measurement results are presented in fig. 2. At first they were a bit surprising, as it was expected that at low light intensities (but high enough to obtain stable oscillations) the frequency of the oscillations should be close to the resonance frequency of the cell, and that it should shift away from the resonance frequency with increase of the light intensity. Such a behavior would be to some extent similar to the effects that can be observed in electronic sine wave generators, where module of the $K\beta$ is selected as slightly higher than 1 (the circuit works then with such an output amplitude at which, due to non-linearities, module of the $K\beta$ is bounded by 1) in order to obtain stable oscillations, but then any increase of the gain K (meaning also rise of the $K\beta$ module, that is calculatedassuming linear operation of the circuit) results in greater distortions of the output signal and shifts it away from the resonance frequency of the LC circuit.

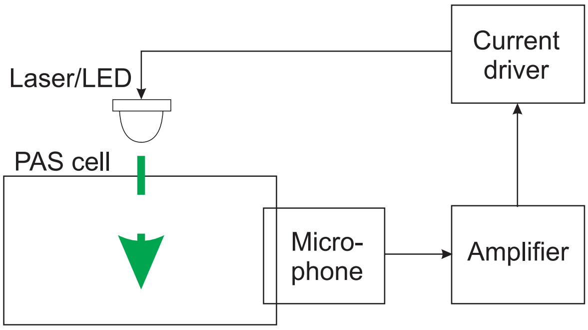

Fig. 3. Block structure of a photoacoustic generator working in a sine wave mode.

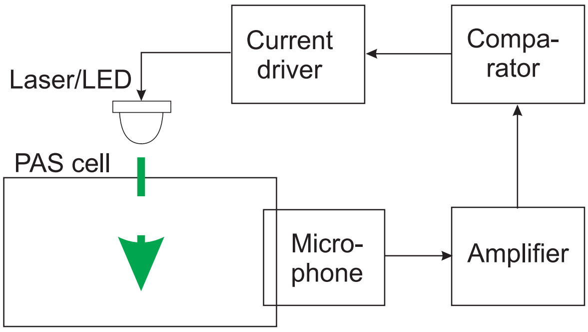

Fig. 4. Implemented structure of the photoacoustic generator.

Reasons for such a behavior of the designed setup became clear after careful analysis of the design. It should be noticed that correct implementation of a photoacoustic generator according to the mentioned concept of sine wave generation should have a structure as in fig. 3, while the implemented setup had a structure as in fig. 4. In order to drive the light source a saturated switch was used, which in turn had to be controlled by a comparator. As a result, the structure in fig. 4 lacks a basic feature required from a sine wave generator, in which startup of the oscillations results from linear amplification, while nonlinear effects arise when the signal reaches a large amplitude. The structure in fig. 4 works in a quite opposite manner, as the comparator results in nonlinear operation of the circuit even when the signal is very low, and there is no mechanism to provide self-limitation of the signal gain. As a result, the structure of fig. 4 can be considered a kind of relaxation oscillator with a resonance component (the cell) introduced into the feedback loop. Limited Q-factor of the cell resulted in poor filtration of the photoacoustic step response. Output signal from the cell was not sinusoidal and its duty factor was different from 50 percent (fig. 5, 6). As a result, the threshold level of the comparator was different from half of the peak-to-peak level of the signal, introducing additional delay that led to an extra phase shift of the signal. This phase shift was probably the main reason for detuning the photoacoustic generator from the resonance frequency of the photoacoustic cell.

4 Conclusions

The described experiment, although a bit different from the intended approach, led to a few important conclusions. From the obtained results it can be stated, that a photoacoustic oscillator can be implemented in at least two different ways – as a sine generator or astable (relaxation) oscillator. The conducted measurements gave a preliminary idea of how the light intensity influences the frequency of the photoacoustic oscillator working in the relaxation mode. Some imperfections of the design that should be corrected in order to obtain a better quality generator were identified. The obtained results proved that both concepts (sinusoidal and astable) of the photoacoustic generator should be further investigated.

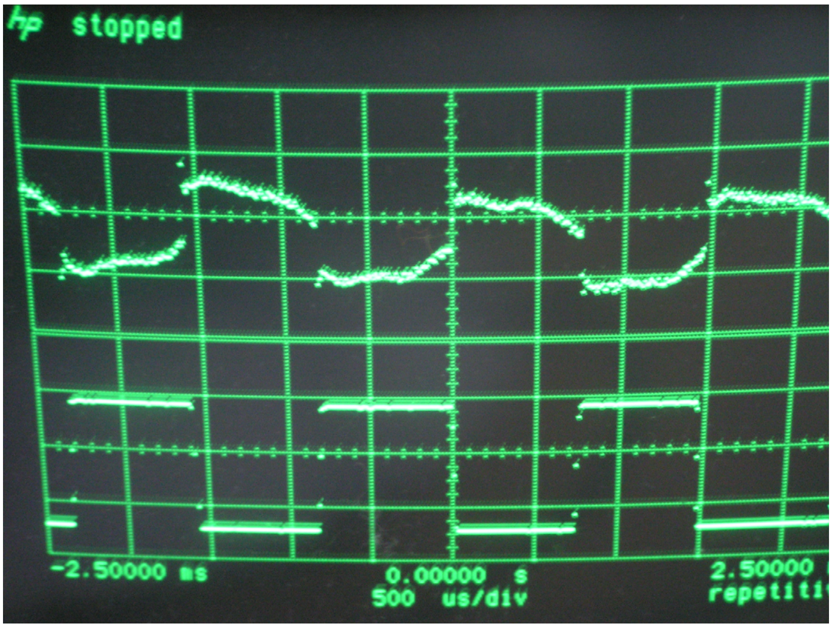

Fig. 5. Signals observed in the photoacoustic generator working at a low level of the light intensity: microphone signal (upper trace), LED switching signal (bottom trace).

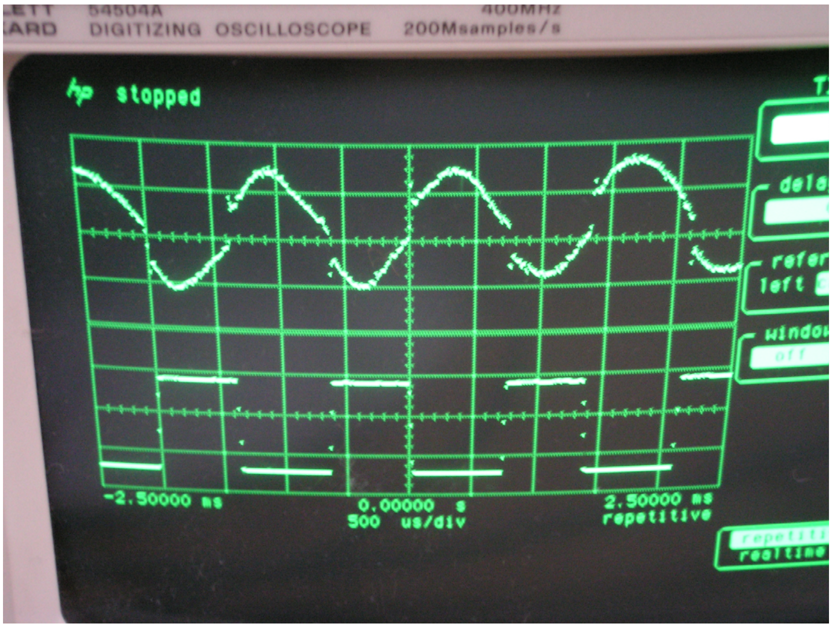

Fig. 6. Signals observed in the photoacoustic generator working at a high level of the light intensity: microphone signal (upper trace), LED switching signal (bottom trace).

References

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