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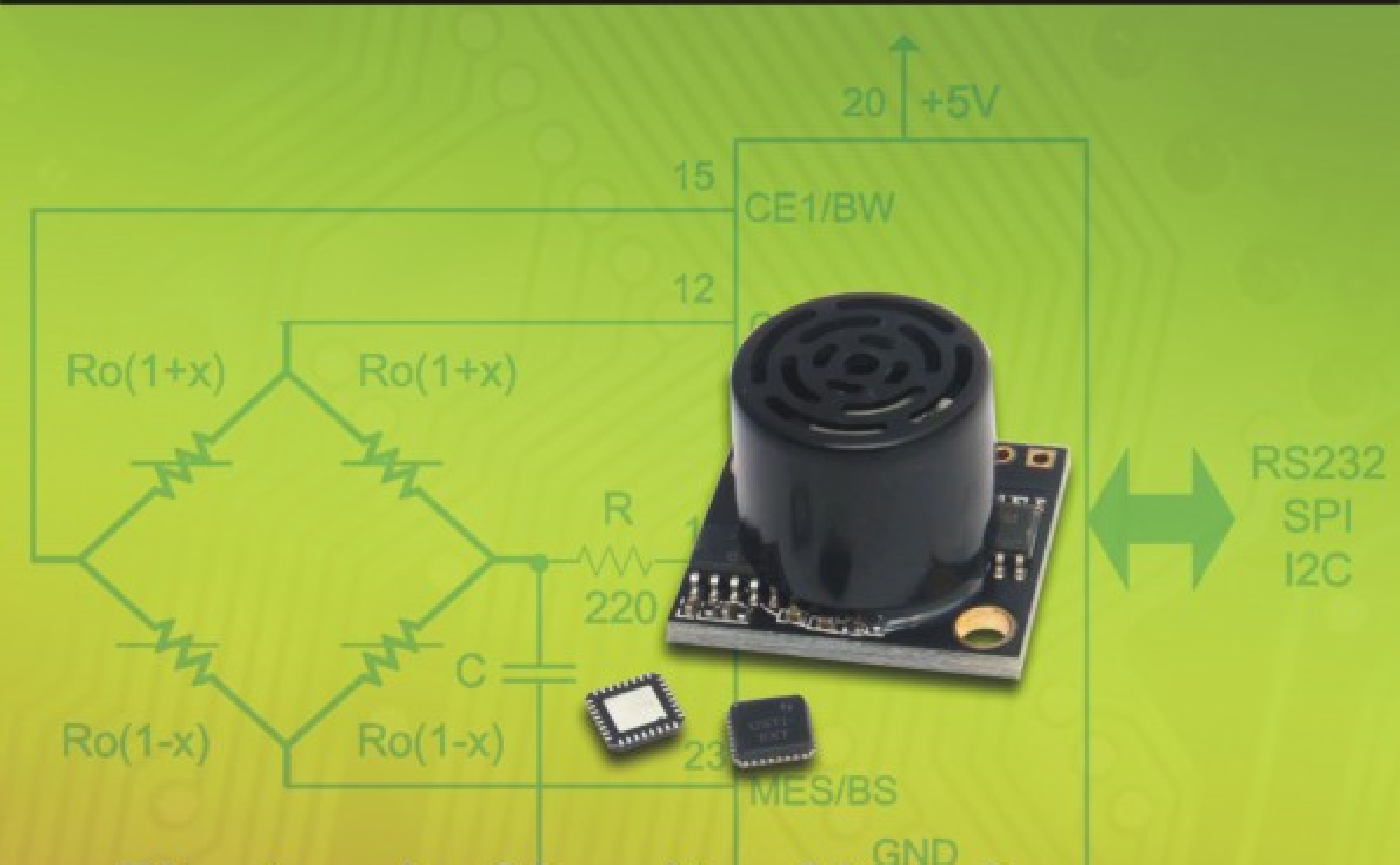

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Design and Development of Microcontroller Based Photoacoustic Spectrometer

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Abstract: The paper describes the design and development of microcontroller based photoacoustic spectrometer (PAS). The photoacoustic (PA) cell designed for the present study is of Helmholtz resonator type with a provision to measure the sample behavior as a function of temperature. In this system, an electret microphone is employed to achieve high signal to noise ratio. The microphone compartment is isolated from the sample compartment to avoid the heating effect of the resistive electric microphone which detects the photoacoustic signal. A two stage preamplifier and tunable band-pass filter have been designed with a low noise op-amp LM308. C8051F060 microcontroller has been used to acquire and process the signal from photoacoustic cell. The frequency response of the cell is studied with carbon-black as a sample. The resonant frequency of cell was found at 330 Hz. The system is very compact and easy to carry the experiments. *Copyright © 2012 IFSA.*

Keywords: Photoacoustic, Spectrometer, PA Cell, C8051F060.

1. Introduction

Besides several well established methods such as Nuclear Magnetic Resonance, Differential Scanning Calorimetry, Thermal Microscopy etc., the PA technique has also gained wide importance as a powerful tool for the study of phase transition in solids. The wealth information contained in the PA signal can be used to investigate the variations in the optical and thermal properties of materials during phase transitions. The PA technique basically no-contact and non-destructive in nature and offers several advantages such as relative easy in sample preparation, the range of samples that can be studied etc. In general several reports have been available on the use of PA technique for the investigation of phase transitions in solids [1-10]. Few authors report the application of PA effect to study the phase transitions and thermal properties of liquid crystals [11-12]. Though the photoacoustic spectroscopy was discovered in 1880 by Graham Bell, it has gained momentum only after invention of microphone and laser. Several researchers have improved the basic PAS technique by incorporating several modifications in the PA cell design, radiation sources, detectors, data acquisition and processing systems etc. The use of laser as an exciting source in gas photoacoustic systems was first reported by Kerr and Altwood [13] and has subsequently described by numerous other authors aiming at signal amplitude enhancement, noise reduction, compactness and provision to study the sample properties as a function of temperature [14-20]. The relative simplicity of the experimental method, high sensitivity and the ease of interpretation of results make it an ideal technique for finding the thermal characteristics of the materials.

2. Principle

Photoacoustic (PA) effect is basically generation of acoustic waves on irradiating certain substances by a modulated radiation source. Thus, when the sample is irradiated by modulated electromagnetic wave, absorption of photons (photo energy) generates excited internal energy levels. All or part of the absorbed photon energy is then transformed into heat (thermal energy) through non-radioactive relaxation processes in the sample. In solids or liquids it appears as vibrational energy of ions or atoms. Since, the radiation incident on the sample is intensity modulated, the internal heating of the sample is also modulated at the same frequency. The air at the sample and gas interface undergoes compression and rarefactions by this internal heating of the sample, which in turn produces acoustic signal of same frequency as that of the modulating signal [21].

The Fig. 1 shows the block diagram of microcontroller based photoacoustic spectrometer. It consists of 10 mW (830 nm) IR laser source, PA cell, microphone, pre-amplifier, band-pass filter and microcontroller with LCD module, buffer, and comparator driver.

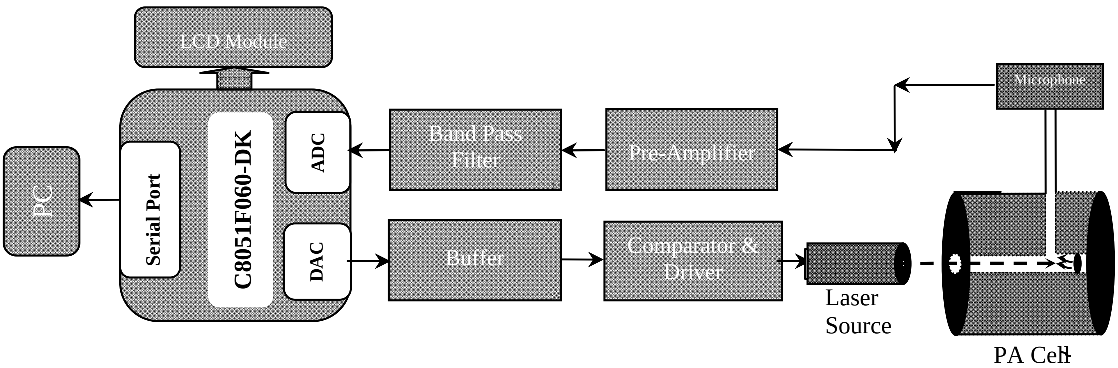

Fig. 1. Block Diagram of Microcontroller based Photoacoustic Spectrometer.

3. Photoacoustic Cell

Fig. 2 shows the schematic of PA cell. The cell design can be considered as the heart of the PAS and ultimate aim in cell design is maximizing the signal to noise ratio. The PA cell used in the present study is designed according to the Helmholtz resonance principle [12]. It has been constructed with a view to achieve high sensitivity and expanded operating range for the temperature up to 500 °C and frequency up to 1 kHz specially for the study of phase transitions in solids. The cell is made from stainless steel cylindrical block of dimension 5cm length, 4.8 cm diameter and 1.2 cm inner diameter. A cylindered tube of 2.0 mm inner diameter and 8.0 cm length is welded near sample cavity, which acts as resonating column of the cell. The microphone chamber (3 cm length, 3 cm diameter and 1 cm inner diameter for placing microphone) is welded on top of the tube, which acts as acoustic signal detector. There is a glass window for laser source to enter and fall on sample cavity. The glass windows are fitted air tight with rubber O-ring and align screws. Similarly, a rubber O-ring is employed in the microphone chamber to arrest air leakages.

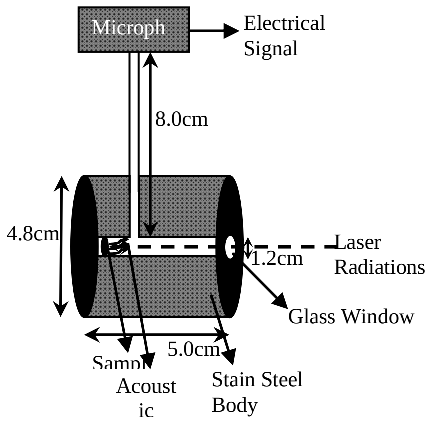

Fig. 2. Schematic of PA cell.

4. IR Laser Source

Incandescent lamps or arc lamps are normally used as radiation source for PA studies. But lasers have found wide acceptance as convenient radiation sources in PA studies owing to their highly collimated beam of extremely high spectral brilliance [22]. A switchable diode laser with following specifications has been used for the present study.

Table 1. Specifications of switchable diode laser.

Type	**Switchable Diode Laser**
Power	10 mW
Wavelength	830 nm
Switching voltage	TTL signal

The laser beam is modulated by connecting diode laser in the collector of a transistor and modulating signal (TTL square wave) applied to the base of the transistor as shown in Fig. 3.

5. Detector

An electret microphone has been employed for the present work. It works on the same principle as the condenser, but with the difference that the capacitance is provided by the electret, which is a thin foil of material with a permanent electrical polarization and high dielectric constant. One side of the electret foil is metalized and the insulating side is placed on a fixed back plate.

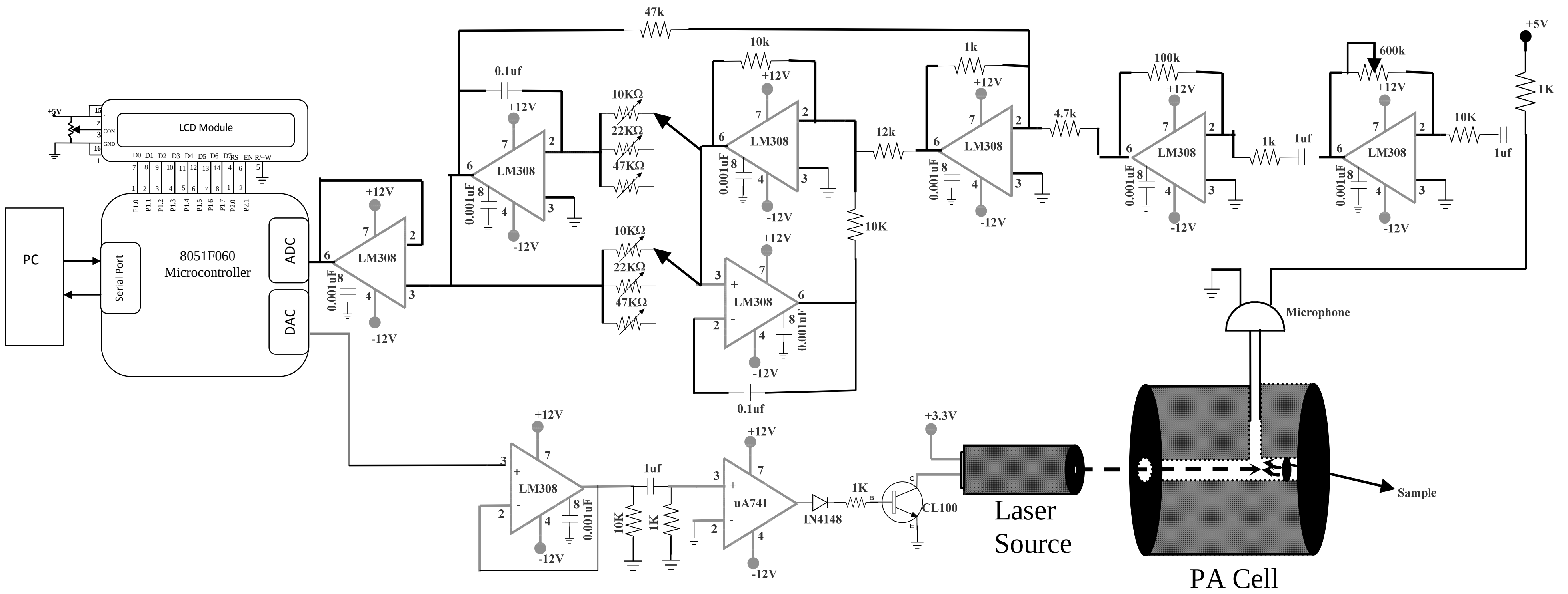

Fig. 3. Complete Schematic of the System.

The impinging sound waves on the metalized foil cause a change in polarization characteristics of the electret material which in turn provides small voltage between the metalized front electret and the fixed back plate. KECG3644PFJ –an electret microphone of KSA Electronics make is employed for the present study. It can be operated with supply voltage ranging from 3 to 10 V. Its output impedance is about 2.2 k and sensitivity is -44±3 dB [23].

6. Pre-amplifier

The photoacoustic effect is based on the absorption of light energy by a sample resulting in the production of a very low amplitude signal. Hence, a pre-amplifier with high input impedance, high gain, and low noise is required to amplify such signals. Fig. 3 shows a pre-amplifier designed using low noise op-amp (LM308) for amplifying the PA signal generated by the electret microphone. The pre-amplifier is designed with two stages to improve the gain-bandwidth product of the amplifier. The pre-amplifier has gain of 10 at first stage and 100 at second stage with total gain of 1000.

7. Band-pass Filter

The signal to noise ratio is the most important parameter that needs to be considered in the PAS, hence the use of signal filter becomes a necessity when low level measurements or high resolution measurements are attempted. The Fig. 3 shows the state-variable tunable band-pass filter for the present system. The state-variable filters, in spite of large number of components, are a good choice for very high Q band-pass filters. The important advantage of the circuit is that, its bandwidth can be adjusted without affecting the mid range gain. In fact Q and gain G, and central frequency f_o can be set with single component. The present circuit is designed for Q=50 and G=10. In this circuit a ganged potentiometer is used as desired $R_{f.}$ By varying the ganged potentiometer, center frequency can be adjusted to the desired value. With this arrangement the frequency range from 10 Hz to 1 kHz can be covered which is well beyond the range required for the present study.

8. Microcontroller

C8051F060 microcontroller has been employed in the present system. This microcontroller is a good example for system-on-chip. It contains all the features to design a single chip instrument. C8051F060 microcontroller has the following important features [24].

- High-speed pipelined 8051-compatible CIP-51 microcontroller core (up to 25 MIPS);
- Two 16-bit 1 MSPS ADCs with a Direct Memory Access controller;
- Two 12-bit DACs with programmable update scheduling;
- 64KB of in-system programmable Flash memory;
- 4352 (4096 + 256) bytes of on-chip RAM;
- External Data Memory Interface with 64KB direct address space;
- SPI, SM Bus/I^2C, and two UART serial interfaces implemented in hardware;
- Five general purpose 16-bit Timers;
- Programmable Counter/Timer Array with six capture/compare modules;
- On-chip Watchdog Timer, VDD Monitor, and Temperature Sensor;

In the present study C8051F060DK microcontroller kit has been employed.

9. Software Feature of the System

The flowchart of the program is shown in Fig. 4. The software is written in embedded ‘C’ language using Silicon Laboratories’ integrated development environment and Keil full-version embedded ‘C’ cross compiler. The program first initializes the on-chip peripherals viz., ADC0, DAC0, UART0, and LCD module. After initialization the program generates sine wave with the help of on-chip DAC0 and Timer-3 module of microcontroller. The sine codes are placed in the look-up table, these sine codes are scheduled updated to DAC using Timer-3. The Timer-3 is programmed to generate an interrupt every 10 µsec. When interrupt occurs, the program reads the sine code from table by calculating the step through phase accumulator and sends to DAC0 module. By varying the step size, the frequency of sine wave thus generated can be varied. After generating sine wave, the program reads the PA signal through ADC0 module and calculates the amplitude of the signal by taking the average of many waves and displays on the LCD module, this process will eliminate random noise. Finally, it checks the P3.7 port line for a valid key-press. If the key is pressed then it sends the amplitude data to personal computer through UART0 of microcontroller. Then, the above procedure is repeated continuously to measure and display the amplitude of the signal.

10. Working of the System

The complete schematic of the system is shown in Fig. 3. Carbon soot quoted on glass plate of 1.0 cm diameter, acts as a sample, is placed in the sample cavity of the PA cell. Initially, the microcontroller generates square wave signal by the on-chip D/A converter and comparator. This signal is applied to the base of transistor to modulate the diode laser source, which is connected to the collector of the transistor. When modulated laser beam falls on the surface of the carbon black, produces an acoustic signal of same frequency as that of the modulating signal. This acoustic signal is converted into electrical signal by the microphone. This microphone signal is usually small in amplitude, hence it is amplified by the pre-amplifier and filter. The latter will improve the signal to noise ratio of the circuit. The signal is then acquired by the on-chip 16-bit A/D converter. The on-chip A/D converter is unipolar, hence the signal applied to this A/D converter should be unipolar. The C8051F060-DK board contains signal shifting circuits which shift DC level of the signal to convert into unipolar signal. The digital data acquired is then processed for finding the amplitude of the signal and displayed on the LCD module. The data will be communicated and stored in the PC through the serial port provided on the system. Provision is made to study the sample characteristics as a function of temperature.

11. Results and Conclusions

The Fig. 5 shows the frequency response of the photoacoustic cell. The Fig. 6 shows the photograph of the complete system. The modulating frequency is varied from 10 Hz to 1 kHz and amplitude of the signal is measured as a function of frequency. Graph is drawn between the frequency and amplitude of the signal. The graph shows that the signal amplitude is maximum at 330 Hz. Photograph of the system clearly indicates that signal appears $2V_{PP}$ on the oscilloscope at 330 Hz. The system is very compact and easy to carry the experiments and its low cost makes it ideal for phase transition studies. The design of lock-in amplifier for the present instrument is under progress. After designing, the instrument will be employed to study the phase transitions of different samples.

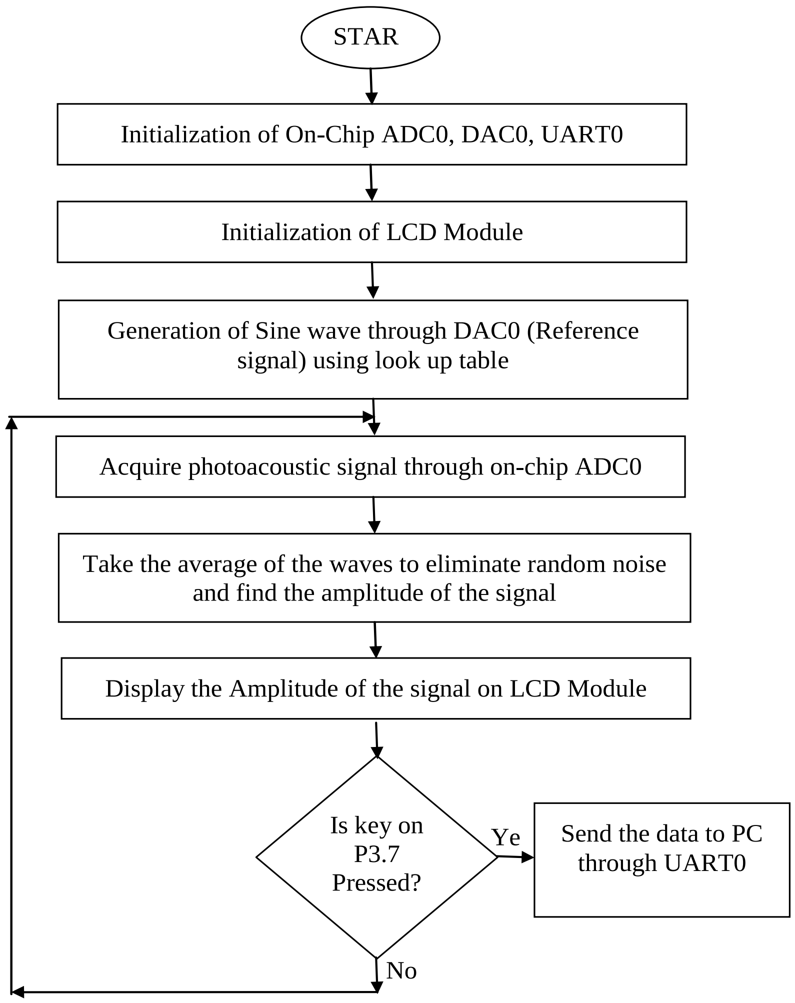

Fig. 4. Flow chart of the system.

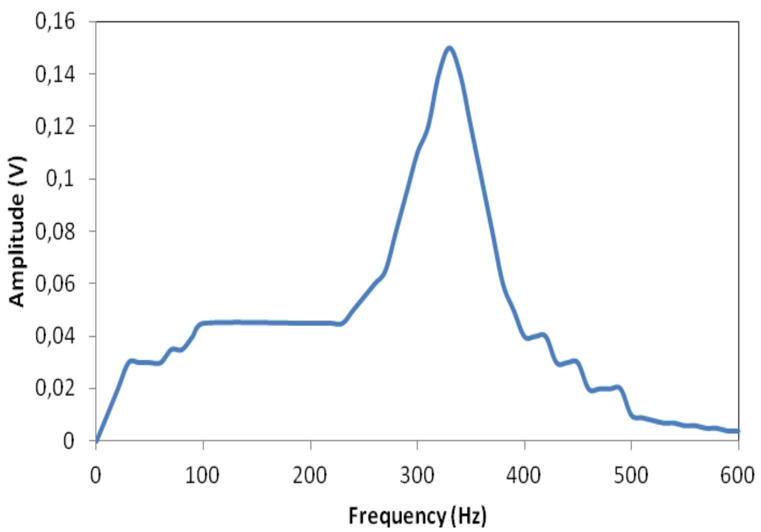

Fig. 5. Frequency response of the photoacoustic cell.

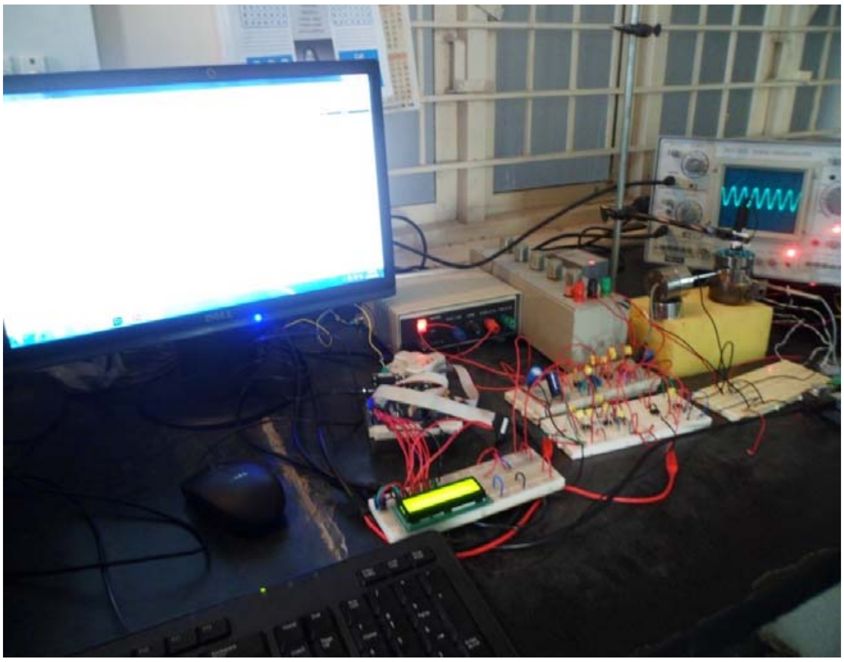

Fig. 6. Photograph of the complete system.

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Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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