Electronic Journal «Technical Acoustics»
http://www.ejta.org
2005, 37

Y. B. Gandole[1], S. P. Yawale[2], S. S. Yawale[2]

[1] *Dept. of Electronics, Adarsha Science J. B. Arts and Birla Commerce, Mahavidyalaya Dhamangaon Rly. Distt. Amravati - 444 709, India. e-mail: ygandole@indiatimes.com*
[2] *Dept. of Physics and Electronics, Government Vidarbha Institute of Science and Humanities, Amravati - 444 604, India, e-mail: spyawale@rediffmail.com*

Simplified instrumentation for ultrasonic measurements

Received 18.10.2005, published 04.12.2005

Simplified instrumentation for ultrasonic measurements to generate and detect ultrasonic pulses in liquids and solids is described. High frequency pulse generator is assembled using integrated circuits (74LS00, 74LS90, 74LS93, 4093, 74121 and 7407), which generates variable frequencies (0.625, 1, 1.25, 2.5, 5 and 10 MHz), having pulse width 2 microseconds to 60 microseconds. The wideband receiver is developed using radio frequency amplifier (IC CA3028), zero-cross detector (LM393), and buffer amplifier (AD 826). The gain and bandwidth of the receiver are 50 dB and 15 MHz respectively. Transit time measurement has been taken on personal computer using analog to digital converter card. The system is found suitable, accurate and versatile for ultrasonic velocity and attenuation measurements.

INTRODUCTION

There has been an increasing application of ultrasonic velocity measurements for non-destructive characterization of materials. Ultrasonic velocity measurements are useful for determining several important material parameters like moduli, poison's ratio, residual stresses, texture, porosity and characterization of secondary phases in microstructure, etc. [1], [2] and [3]. In order to study the small and important variations, high-resolution techniques for ultrasonic velocity measurements are necessary.

Recently various pulse methods have used for velocity measurements. It is possible to measure the time, which a pulse requires to travel forth and back. The electronic time mark on an oscilloscope can be used for time measurement. The precision of this method is few parts per thousandth. To measure absorption coefficient, a crystal receives the waves reflected by the reflector, which usually is the same as source. On an oscilloscope it is then possible to see a series of echoes due to the traveling back and forth of the wave packet whose distance on the calibrated time axis is proportional to the distance between source and reflector. Moving the reflector, the echoes changes their position and size on the oscilloscope screen and this allows determination of absorption coefficient [4].

A number of approaches are available for the measurement of ultrasonic velocity and attenuation in materials. Some of the standard techniques for the measurement of ultrasonic velocity are: sing-around, pulse-echo, interferometer, and diffraction techniques. The sing-around technique is accurate for measurements of ultrasonic velocity. This can be described by Beyer et al. [5], Satyabala et al. [6] and Soitkar et al. [7].

The ultrasonic pulse-echo-overlap technique is widely used, as it is accurate and versatile. This method is efficient in measuring velocity only when the two echoes have similar features. In the case of strong dispersive materials, this method fails to give unambiguous results. This problem can be overcome by adopting "phase slope" method in which echoes are analyzed in frequency domain. In this method, the whole ultrasonic pulse is taken into account instead of only one point (peak amplitude, zero crossing etc.). Though this method is found to be better than the "pulse-echoes-overlap" method, it yields poor results when the signal to noise ratio of the echoes is low such, as is the case with composite materials, coarse grained and dispersive materials [2].

Popadakis [8], Chung et al. [9] and Hellier et al. [10] have presented the circuits of pulse-echo-overlap techniques. This pulse-echoes technique is used by Aggarwal et al. [11] and Suc-Kyoung et al. [12] for ultrasonic measurements. Recently several new pulse techniques, with externally high degree of precision have been developed for ultrasonic studies. More advanced technique for ultrasonic measurements was reviewed by Dignum [13], Canxia Kan et al. [14], and Dixon et al. [15]. A solid-state pulser-receiver system for ultrasonic velocity measurements at fixed frequency using digital circuitry has been developed by Agnihotri et al. [4]. A solid-state variable frequency pulser-receiver system has been developed by Yawale et al. [16].

The current work applies the approach of Yawale et al. [16] with modification in pulser and receiver design for precise velocity and attenuation measurements. The transmitting and received pulse is displayed on personal computer using ADC card. The system has been developed using concept of virtual instrumentation and found suitable, accurate and versatile for ultrasonic velocity and attenuation measurements.

1. INSTRUMENTATION

The block diagram of pulse sender-receiver system is shown in figure 1. The high frequency pulse generator generates sharp radio frequency pulses of various frequencies (0.625, 1, 1.125, 2.5, 5 and 10 MHz) having pulse width 2 to 60 μs. The repetition rate of the pulses is 1 KHz. This high frequency pulse is fed to the ultrasonic transducer (Tx) having resonant frequency 2.5 MHz and 25.4 mm diameter. The matched pair of quartz transducers completely sealed (supplied by electrosonic industries, New Delhi) was used for ultrasonic pulse generation and detection. The receiver-transducer (Rx), which is at the other end of the sample, converts the received ultrasonic pulse into an electrical signal. This signal is fed to an amplifier and then detected. This detected pulse is used to reset the RS flip-flop and sender pulse is used to set the RS flip-flop. Hence the width of the pulse at the output of RS flip-flop gives the time required to reach the pulse at the receiver-transducer (Rx). The transmitting and received pulse is displayed on PC using ADC card.

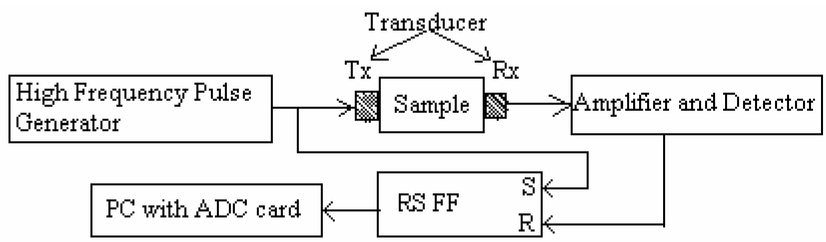

Figure 1. Block diagram of pulse sender-receiver system

1.1. Pulse generator

Figure 2 shows the circuit diagram of high frequency pulse generator. Using integrated circuit 74LS00 and a 10 MHz quartz crystal, assembles a crystal oscillator circuit. Frequency division is achieved by 74LS90 and 74LS93. 1 KHz clock pulse is generated using Schmitt trigger NAND gate (4093), whose width is controlled by 74121 (monostable multivibrator). The pulse width can be varied from 2 to 60 μs with the help of potentiometer of 1 MΩ and capacitor 100 pF between pin 11 and 10 of 74121. The output of 74121 and various frequency signals are applied to the AND gate. The resulting pulse is then fed to 7407 (Hex buffer) with pull up resistor and 20 V supply. The amplitude of output pulse uses 10 V peak to peak; which is given to sender transducer (Tx). The resulting waveforms are shown in figure 5.

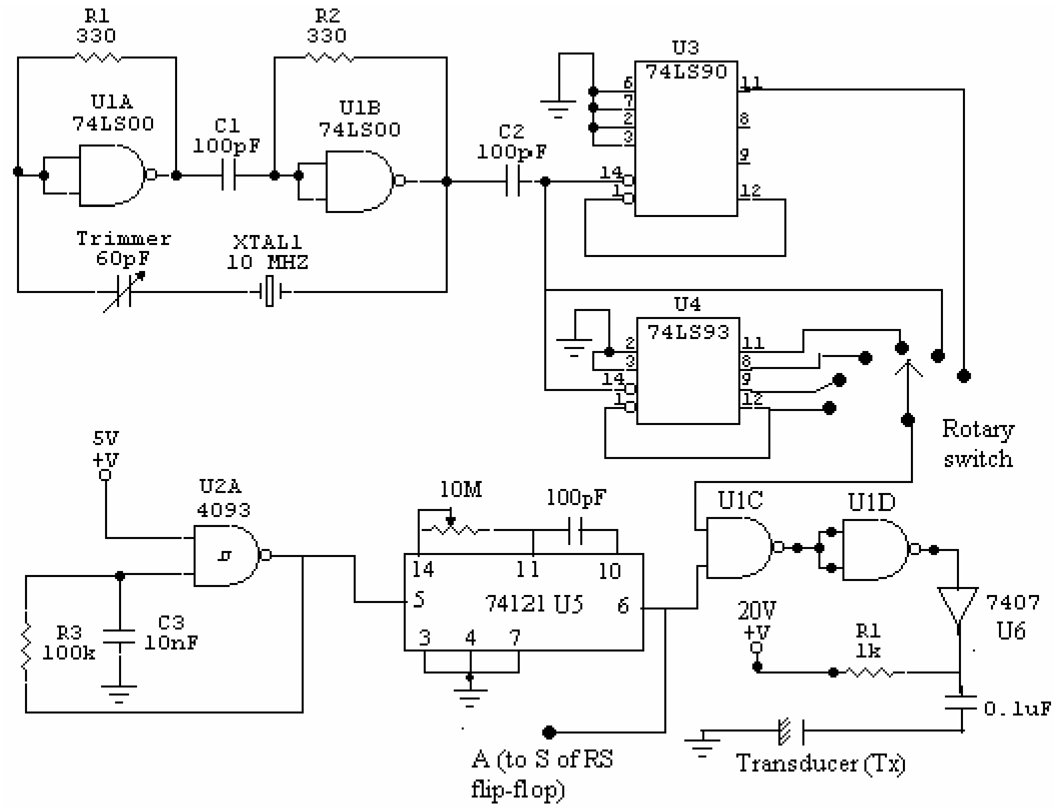

Figure 2. Circuit diagram of high frequency pulse generator

1.2. Receiver

The circuit diagram of wideband receiver is shown in figure 3. An amplifier consists of single stage, which is assembled by using transistor Q1 and Q2 (BF195). The output of single stage amplifier is again amplified with the help of another amplifier using IC CA3028 in cascade mode. The overall characteristics of amplifier are as: gain is 50 dB, bandwidth is 15 MHz, input impedance is 10.5 kΩ and low noise. The stability of IC 3028 amplifier is much higher because of small reverse feedback [17]. After the detection of signal through LM 393 (wide band zero cross detector), the detected signal is fed to unity gain buffer, designed using high speed, low power operational amplifier AD 826. The characteristics of AD 826 are 50 MHz unity gain bandwidth, 350 V/μs slew rate, 70 ns-settling time to 0.01% and 2.0 mV max input offset voltage. This detected signal is then given to reset input of RS flip-flop, while the output of IC 74121 of RF pulse generator is used to set the flip-flop. Therefore a single pulse is obtained at the output, whose width is the time taken by the pulse to travel through the sample.

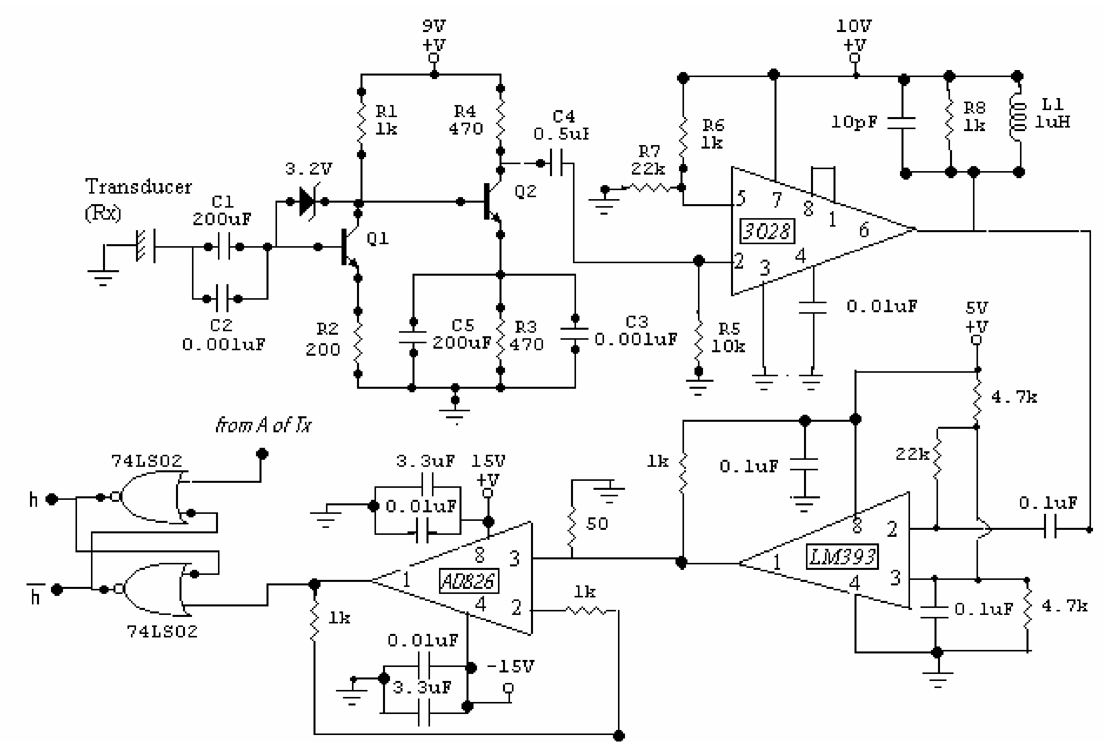

Figure 3. Circuit diagram of receiver

2. MEASUREMENT TECHNIQUE

For the measurement of velocity and attenuation, the sender transducer is firmly fixed at one end of the measuring cell, while receiving transducer is fixed to movable scale (Griffin and Tatlock Ltd. London, maker) having least count 0.0001 cm.

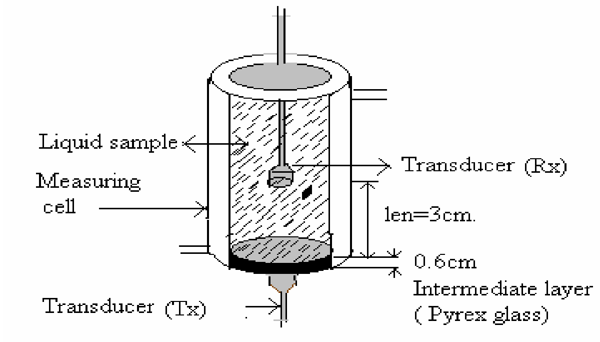

Figure 4.

Probe layout of liquid sample

The liquid sample was contained in a measurement cell as shown in figure 4. A glass bottle of suitable size was cut to form a measuring cell. The bottle was fixed with adhesive araldite in an inner space of double walled chamber which was made up of thick galvanized sheet. Water circulation arrangement was made through thermostat. Dimensions of double walled chamber are as: height of doubled walled chamber 6.5 inches, outer diameter 5.5 inches, inner diameter 3.25 inches, height of glass bottle 7.5 inches. The double walled chamber was provided with inlet and outlet for constant temperature water circulation. The lower surface of cell (glass bottle) and double walled chamber were in the same plane. The double walled chamber was kept on disc to which sender transducer was fixed. Applying silicone grease made the contact of sender transducer and measuring cell. The lower surface of measuring cell acted as acoustic window through which ultrasonic waves could enter in the measuring cell. The clamps ware provided between double walled chamber and disc to avoid movement of doubled walled chamber and hence of measuring cell during the ultrasonic measurements.

Knowing the distance and transit time, ultrasonic velocity can be computed. The transmitting and received pulse is displayed on PC using ADC card.

3. RESULTS AND DISCUSSION

The system is checked by measuring the ultrasonic velocity and attenuation in distilled water, some organic liquids and solids at 5 MHz frequencies and at 25°C temperature. Experimentally, the attenuation in each sample is based on two measurements; one measurement is done without the sample to determine the energy emitted by the transducer, and one is done with the sample present. The signals obtained at different stages of fig. 2 are shown in fig. 5.

Figures 5 and 7 show the received signals without sample and with sample for distilled water and benzene. The distance between transmitting transducer (Tx) and receiving transducer (Rx) is 3 cm. Table 1 shows the comparison between the literature values and measured values of ultrasonic velocity and attenuation for the liquid and solid samples.

The stability, accuracy and sensitivity of the system can be seen from the table 1, It is observed that the experimental values of ultrasonic velocity and attenuation at 5 MHz are found to be in good agreement with literature values. All the measured values are within 0.01 % accuracy. We have used this system for the measurement of ultrasonic velocity and attenuation in different environment conditions, such as change in temperature up to 45^{0}C (keeping the temperature of liquid constant), humidity etc; but no change in velocity is observed. This shows that the system is less susceptible to the temperature changes and hence it is stable. Thus the system shows good performance.

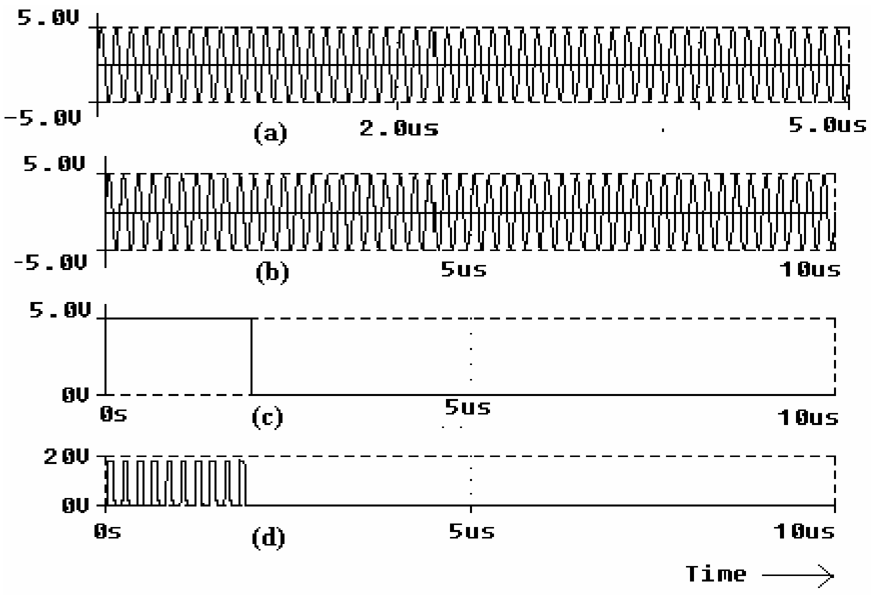

Figure 5. (a) Signal at the output of U1B (10MHz), (b) Signal at pin No.12 of U4 (7493) (5MHz), (c) 2 μs pulse at pin No. 6 of U5 (74121), (d) Signal at pin No. 2 of U6 (5MHz)

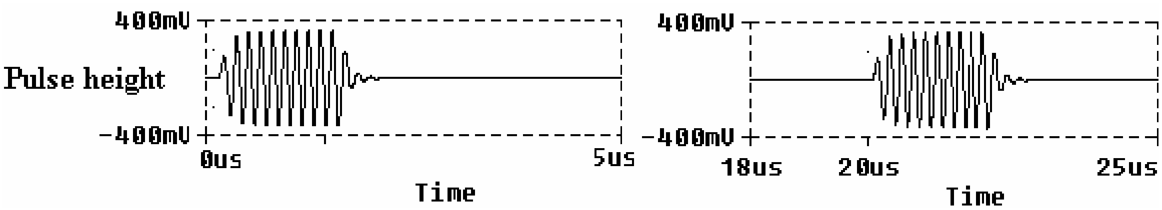

Figure 6. Received signal without sample (a) and with sample (b) (distilled water)

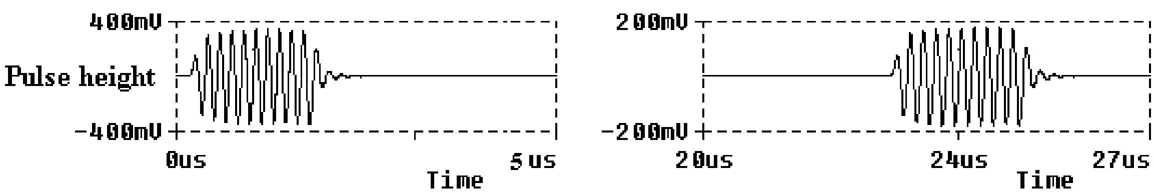

Figure 7. Received signal without sample (a) and with sample (b) (benzene)

Table 1. Ultrasonic velocity and attenuation at 25°C for 5 MHz frequency

Liquid					
S. No.	Sample	Velocity (m/s)		Attenuation ($\propto/f^2$) 10^{-15} s^2/m	
		Experimental	Literature value	Experimental	Literature value
1	Ethanol	1207.641	1207 [30]	49.305	48.5 [30]
2	Methanol	1103.354	1103 [30]	31.937	30.2 [30], [19]
3	Carbon tetrachloride	930.411	930 [30]	539.102	538 [30], 545 [18]
4	Acetone	1174.516	1174 [29]	54.680	54 [29], 30 [20]
5	Benzene	1310.043	1310 [30]	873.277	873 [30]
6	Distilled water	1497.005	1497 [30]	23.252	22 [30]
Solids					
S. No.	Sample	Velocity (m/s)		Attenuation (dB/cm)	
		Experimental	Literature value	Experimental	Literature value
7	Polyethylene	2560.834	2561.20 [16]	28.40	26.5 [30]
8	Teflon	1400.110	1400.31 [16]	4.20	3.9 [30]

ACKNOWLEDGEMENTS

One of the author (Y. B.Gandole) like to acknowledge University Grant Commission (New Delhi, India), for granting the FIP Fellowship under X^{th} plan. We would like to thank Director, Head of the department and teacher fellows of department of Physics, Government Vidarbha Institute of Science and Humanities, Amravati, for support of this work

REFERENCES

[1] Green R. E. Jr. NDE: Material Charactererisation and Reliability Strategies. Eds. O. Buck and S. M. Wolf, 115–132, 1981.

Hull D. R., Kaultz H. E., A. Vary. Measurement of Ultrasonic velocity using Phase-slop and Cross-correlation Methods. Materials Evaluation, 43, 1455–1460, 1985.

[3] Jayakumar T., Baldev Raj, Willems H., Arnold W. Influence of microstructure on ultrasonic velocity in Nimonic Alloy PE-16. Proc. Review of Progress in QNDE. Edited by D. O. Thompson and Chimenti, Plenum Press, New York, 10, 1693–1700, 1990.

[4] Agnihotri P. K., Adgaonkar C. S. Theoretical evaluation of ultrasonic velocity in binary liquid mixtures. Research and Industry, 33, 139, 1988.

[5] Beyer R. T., Letcher S. V. Physical ultrasonic. Academic Press, New York, p. 87, 1969.

[6] Satyabala S. P., Rao M., Suryanarayana M. Sing-around technique of determining ultrasonic velocity in liquids using a single transducer. Acoust. lett., 2, 29, 1978.

[7] Soitkar V. S., Sunnapwar K. P., Navaneet G. N. Receiving Systems design for Sing-around Technique in Ultrasonic Measurements. Indian J. Tech., 18, 469, 1980.

[8] Papadakies P, New, compact instrument for pulse-echo-overlap measurements of ultrasonic wave transit times. Rev Sci. Instrum., 47, 806, 1976.

[9] Chung D. H., Silversmit D. J., Chick B. B. A Modified Ultrasonic Pulse-Echo-Overlap Method for Determining Sound Velocities and Attenuation of Solids. Rev. Sci. Instrum., 40, 718, 1969.

[10] Hellier A. G., Palmer S. B., Whitehead D. G. An integrated circuit pulse echo overlap facility for measurement of velocity of sound (applied to study of magnetic phase change). Journal of Physics E: Scientific Instrument. 8, 352-354, 1975.

[11] Aggarwal V. C., Gupta A. K. Acoustic attenuation and velocity measurements in a methanol and cyclohexane critical mixture. J. Phys. D: Appl. Phys., 8, 2232–2236, 1975.

[12] Suc-Kyoung Hong, Young Gie Ohr. Ultrasonic speckle pattern correlation interferometry using a pulse-echo method. J. Phys. D: Appl. Phys., 31, 1392–1396, 1998.

[13] Dignum R. Brief Review of Ultrasonic Attenuation with Some Emphasis on Work at Ultrahigh Frequency. Am. J. Phys., 32, 507, 1964.

[14] Canxia Kan, Weiping Cai, Cuncheng Li, Lide Zhang, H Hofmeister. Ultrasonic synthesis and optical properties of Au/Pd bimetallic nanoparticles in ethylene glycol. J. Phys. D: Appl. Phys., 36, 1609–1614, 2003.

[15] Dixon S., Edwards C., Palmer S. B., Reed J. Ultrasonic generation using a plasma igniter. J. Phys. D: Appl. Phys., 34, 1075–1082, 2001.

[16] Yawale S. P., Pakade S. V. Solid state variable frequency pulser-receiver system for ultrasonic measurements. Indian J. of pure & App. Phys., 33, 638–642, 1995.

[17] Millman J., Halkias C. Integrated electronics. Mc Hill Ltd, Tokyo, p. 560, 1972.

[18] A. A. Berdyev, B. Khemraev. Method of investigating the acoustical properties of liquids at frequencies of 300–1000 Mc, Russian J. Phys. Chem., 41, 1490, 1967.

[19] D. E. Gray. American Institute of Physics Handbook, 3rd ed., Mc Graw-Hill, New York, 1972.

[20] D. F. Evans, J. Thomas, J. A. Nadas, M. A. Matesich. Conductance of electrolytes in acetone and in 1-propanol-acetone mixtures at 25°deg. J. Phys. Chem., 75, 1714, 1971.

[21] Gorodetsky G., Lochterman I. Pulse-echo ultrasonic interferometer for the automatic measurements of velocity and attenuation changes. Rev. Sci., Instrum., 52, 1386, 1981.

[22] Malcolm Povey, Ultrasonic Techniques for Fluids Characterization, ISBN 0-12-563730-6, 214, 1997.

[23] Mukherjee S., Basu C., Ghosh U. S. Ultrasonic properties of $V_2O_5P_2O_5$ amorphous materials at different temperatures. J. Non-cryst. Solids, 144, 159, 1992.

[24] Pathak L, Murli N., Amritha V. P. Stand-alone pulse-echo-overlap facility for ultrasonic wave transit time measurements. Rev. Sci. Instrum., 55, 1817, 1984.

[25] Pathak L., Palanisami K. Achieving pulse-echo overlap with scopes having no intensity modulation. Rev. Sci., Instrum., 57, 123, 1986.

[26] San Emeterio J. L., Ramos A., Sanz P. T., Ruiz A., Azbaid A. Modeling NDT piezoelectric ultrasonic transmitters, Rev.: ULTRASONICS, vol. 42, pp. 277–281, 2004

[27] Timrot D. L., Serrendnitskaya M. A., Chkhikvadze T. D., Velocity of sound in liquid sulfur near the lambda-transition point. Sov. Phys. Dokl. 29, 961, 1984.

[28] Vigoureux P. Ultrasonics, Chapman and hall, London, p. 112, 1952.

[29] W. Schaaff, Numerical data and functional relationalships in science and technology, New series group II: Atomic and molecular Physics, vol.5: Molecular Acoustics, Eds: K. H. Hellwege, A. M. Hellweg. Springer-verlag, Berlin, Heidelberg, New York, 1967.

[30] Weast, Robert C. ed. Handbook of Chemistry and Physics. 45th ed., Chemical Rubber Co., Cleveland Ohio, p. E-28. 1964.