MĀPAN - Journal of Metrology Society of India, Vol. 23, No. 4, 2008; pp. 245-252

High Resolution Ultrasonic Attenuation Measurement in Pulse-echo Setup

P.K. DUBEY[1*], S. RAJAGOPALAN[2], V.R. VYAGHRA[2], V.M. PENDSEY[3] and S.J. SHARMA[4]
[1]Radio and Atmospheric Science Division, National Physical Laboratory, New Delhi - 110 012
[2]Department of Electronics, R.S.T.M. Nagpur University Campus, Nagpur - 440 033
[3]Department of Electronics, Sindhu Mahavidyalaya, Nagpur - 440 017
[4]Department of Electronics, S.K. Porwal College, Kamptee, Nagpur - 441 002
*e-mail :premkdubey@gmail.com

[Received : 15.06.2008; Revised : 21.11.2008; Accepted : 04.12.2008]

Abstract

In the present work, a new technique for ultrasonic attenuation measurement in pulse echo setup is designed using off the shelf components. The technique is based on the comparison of echo amplitudes with a programmable reference voltage generated by the personal computer. The designed circuit can measure the echo amplitudes up to seven echoes with a resolution of 4mV, which is sufficient for estimation of ultrasonic attenuation. It does not require the fast analog to digital converters. A program has been developed in "C" to record echo amplitudes and display ultrasonic attenuation on screen. The instrument developed is a stand alone system and does not require any other instrument except PC. The developed technique has been tested for its functionality on some standard liquids.

1. Introduction

Ultrasonic propagation in a medium is characterized by properties of the medium through which it propagates. In low amplitude propagation, the medium affects the wave and the nature of propagating wave is modified. The medium remains in an intrinsic state [1], as against the high-energy ultrasound, which brings about a permanent or semi permanent change when propagated in the medium. The ultrasonic attenuation measurement throws light on parameters like absorption, dispersion and intermolecular interaction and molecular structure of the medium [2-3].

In pulse echo technique, an ultrasonic frequency burst is introduced into the sample using a piezo-electric transducer. The ultrasonic pulse travels through the sample and an echo is registered each time it returns to the transducer. The amplitude of the successive echoes decreases exponentially due to attenuation in the sample [4]. In the conventional pulse echo technique, the amplitudes of the echoes are measured with an oscilloscope or circuits involving peak detector [5-12]. Use of oscilloscope does not improve the result in terms of resolution of the echo amplitude being measured. The resolution in the measurement carried out with oscilloscope depends on

a) The beam focusing quality of the CRO

b) Its amplitude measurement resolution

c) The eyes of user (user with spectacles)

d) The age of CRT. If the oscilloscope is old, then the electron gun will be poor and deteriorate the focusing and contrast of beam.

Most of the above limitations (a and b) can be overcome using a high quality digital storage oscilloscope having better resolution, sampling rate and improved band width. Such as, a Tektronix DSO TDS 2014 (4 channel colour digital storage oscilloscope), has amplitude measurement resolution of 40 mV at 1V/div scale [13].

Due to the technological development in digital computers, its use in measurement and control application has increased tremendously [14]. The basic objective of computer based instrumentation is to improve, the response time, computing power, flexibility and fault tolerance [15-17].

We present here an automatic attenuation measurement circuit which minimizes the error created due to the observer and poor resolution of an oscilloscope and is able to resolve the small variation in echo amplitudes. The computer sets the digital reference voltage (initially a maximum) along with the echo number. The circuit compares echo amplitude with the reference voltage and sends a comparison result signal to PC (whether echo amplitude matched or not). If the amplitude does not match, PC reduces the reference voltage by a step and the process is repeated till it matches with the echo amplitude. This reference voltage is recorded as the amplitude of that echo. The same process is repeated for succeeding echoes.

2. Experimental

2.1 *An ISA Based Digital Input Output Card*

A high-speed data acquisition card has been designed using Intel 8255A with standard ISA interfacing technique [18, 19]. The card has a 16 bit out port and an 8 bit input port. The use of port direction can be programmed. Fig. 1 shows the circuit diagram of the developed card. 10 bits of an out port has been assigned to drive 10 bit DAC and three more bits are used to select the echo number. The bit specification of 16 bit out port is given in Table 1.

2.2 *Pulser- Receiver Module:*

10 MHz RF oscillator has been designed using 10 MHz crystal (Raltron electronics corp. USA) and NOT gates; is shown in fig. 2 [20]. The pulse repetition time generator has been designed using NE566 voltage controlled oscillator for the frequency range of 100Hz to 400Hz (variable). Output of the repetition rate generator drives a gate width controller unit. The gate width controller circuit defines the time for which the 10MHz RF will be transmitted through the sample. It

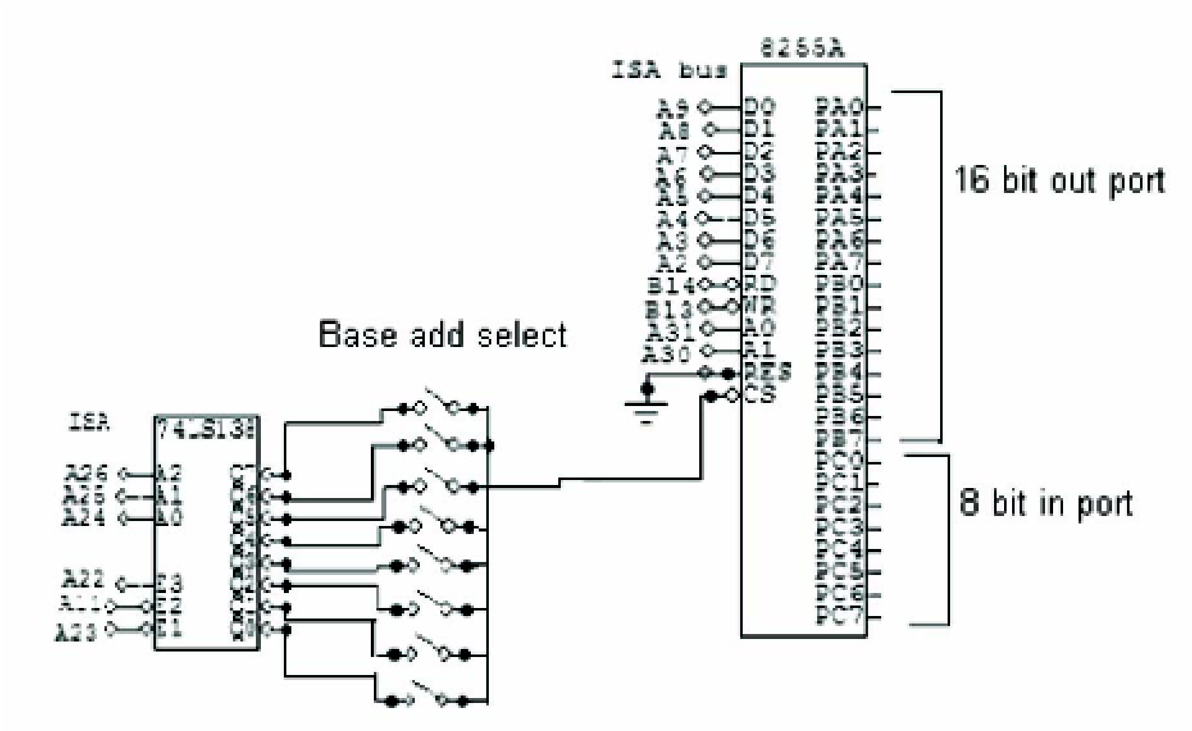

Fig.1. Organization of an ISA Card. 16 bit out port is used for digital reference, echo selection and only one bit of in port is used for echo comparison feedback.

Table 1
Bit specification of 16 bit out port of an ISA card

D_0	Out	Latch bit
$D_3 D_2 D_1$	Out	Echo number specifying bits
$D_{13} D_{12} D_{11} D_{10} D_9 D_8 D_7 D_6 D_5 D_4$	Out	Digital DAC input
$D_{15} D_{14}$	-	Not used.

uses a monostable multivibrator having a time constant of about 1 µs (variable). The output of monostable is fed to the AND gate, whose second input is driven by the RF oscillator. The output of the AND gate thus provides a signal of 10MHz. RF pulse for 1 µs duration with a pulse repetition frequency of 100Hz. The pulsed RF obtained at the output of AND gate is further amplified by transistor amplifier stages. The stages are coupled by a parallel RC element to improve high frequency response of the stage [21]. The final stage of the module is the power amplifier used to increase the current level at the output to drive the circulator. A circulator is a transformer having ferrite core with the three windings [22].

The first winding is excited by the transmitter output, second winding is used to connect the transducer and the third winding provides balanced output for the receiver. The advantages of using a circulator are

- It physically isolates the transmitter and the receiver so that large transmitted pulses will not damage the receiver input.
- It is possible to use single transducer for transmission as well as reception.
- Steps up the transmitted voltage in secondary winding connected to the transducer.
- Provides a differential (balanced) output signal for the receiver.
- Virtually acts as a switch between the transmitter / receiver and the transducer

The center-tapped secondary winding of the circulator provides a differential output voltage to drive the high gain differential amplifier. A single ended output taken from this amplifier (NE592) drives an active detector using a transistor in common

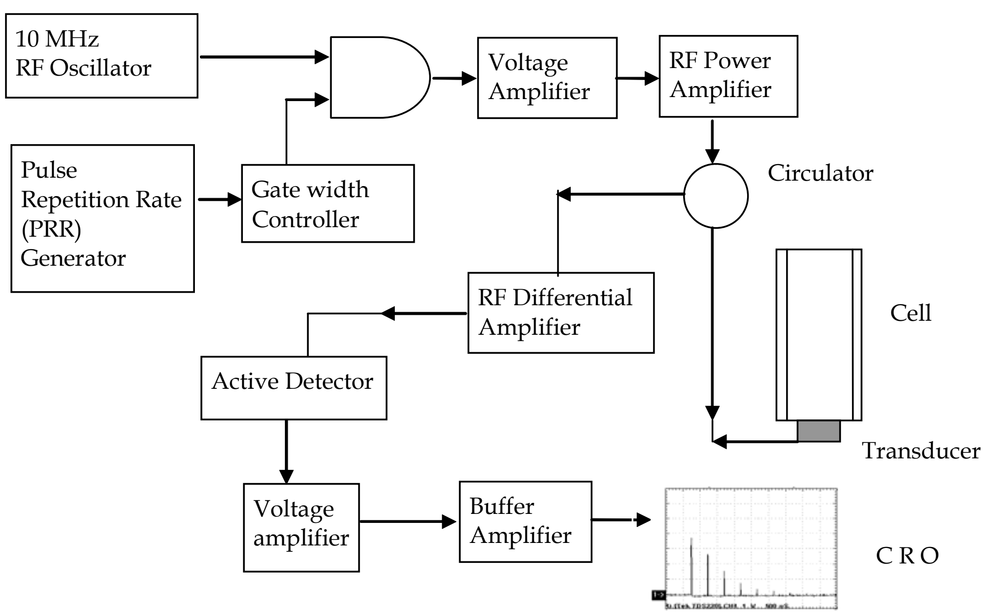

Fig 2. Block diagram of the designed pulser-receiver module

collector mode and parallel RC element at emitter bias. This filters out the 10MHz RF components from the received RF echoes. The detected echoes are further amplified by pre-amplifier, transistor amplifier and buffer at the final stage. The detected echoes output is available at BNC to be fed out CRO for analysis.

2.3 Attenuation Measurement Circuit

Fig. 3 shows the attenuation measurement circuit. The detected echoes are fed to the non inverting terminals of two comparators, IC_1 and IC_2. The first comparator IC_1 (LM 311, ON semiconductor) has inverting terminal at reference voltage of 4V. The inverting terminal of the second comparator IC_2 is driven by a programmable reference voltage (V_{ref}) that can be controlled by PC. If V_{ref} is set at 4V then IC_1 gives a pulse in response to the transmitted pulse, which will reset the counter and decoder (CD4017, Fairchild semiconductor). The reference voltage is reduced by a step of 4mV and is again compared with first echo amplitude. If the amplitude of the first echo is lower than V_{ref}, then IC_2 does not produce a second pulse.

The reference voltage is further reduced by a step of 4mV. This process continues till the programmable Vref coincides with the amplitude of first echo. At this amplitude level the comparator IC_2 will provide second pulse related to the first echo. This pulse would be counted by IC 4017 which sets decoder output (Q_1) high. If the selected echo number is for first echo (i.e. 001 is applied to select lines of MUX), then the high output produced by multiplexer is sensed by an ISA card and reference value is latched in to the PC, corresponding to the amplitude of the first echo. Now, the second echo is selected by Applying 010 to the select lines of IC 74151(TTL 8:1 multiplexer) and the V_{ref} is further reduced in steps of 4mV. If the second echo amplitude coincides with the reference voltage, then the reference is considered as the amplitude of second echo. The above process is repeated for obtaining amplitudes of successive echoes to be recorded into the PC. Fig.4 shows the timing diagram of the comparator circuit.

2.4 Estimation of Ultrasonic Attenuation and Software

The echoes having amplitudes between 20 mV to 4.00V are selected for the estimation of attenuation. The lower amplitude 20mV was chosen to avoid the possibility of electrical noise to be detected as an echo. Let A_1, A_2, …,An be the echo amplitudes (designed for the maximum 7 echoes) detected by the instrument for the echoes e_1, e_2, …,e_n respectively. Then the average ratio (R_{avg}) between the successive echoes is

$$R_{avg} = \left[\frac{\left(\frac{A_1}{A_2} + \frac{A_2}{A_3} + ... \frac{A_{n-1}}{An} \right)}{n-1} \right] \quad (1)$$

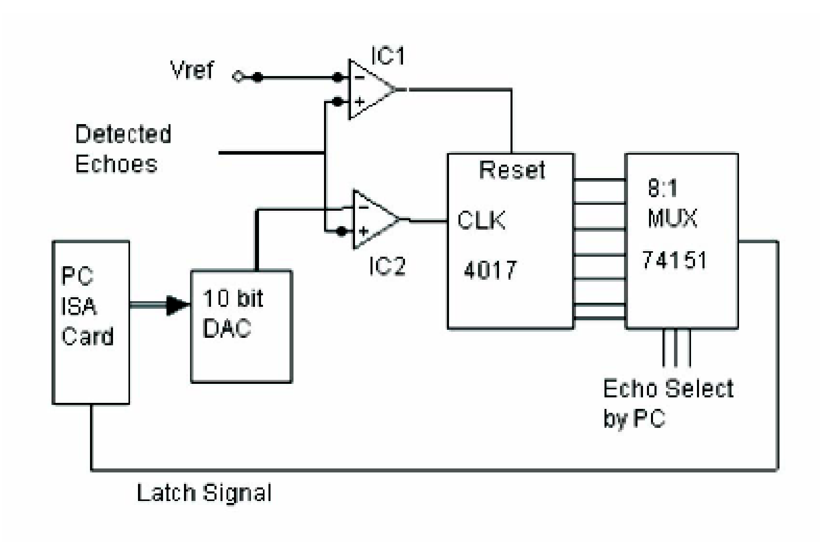

Fig. 3. Schematic diagram of an attenuation measurement circuit

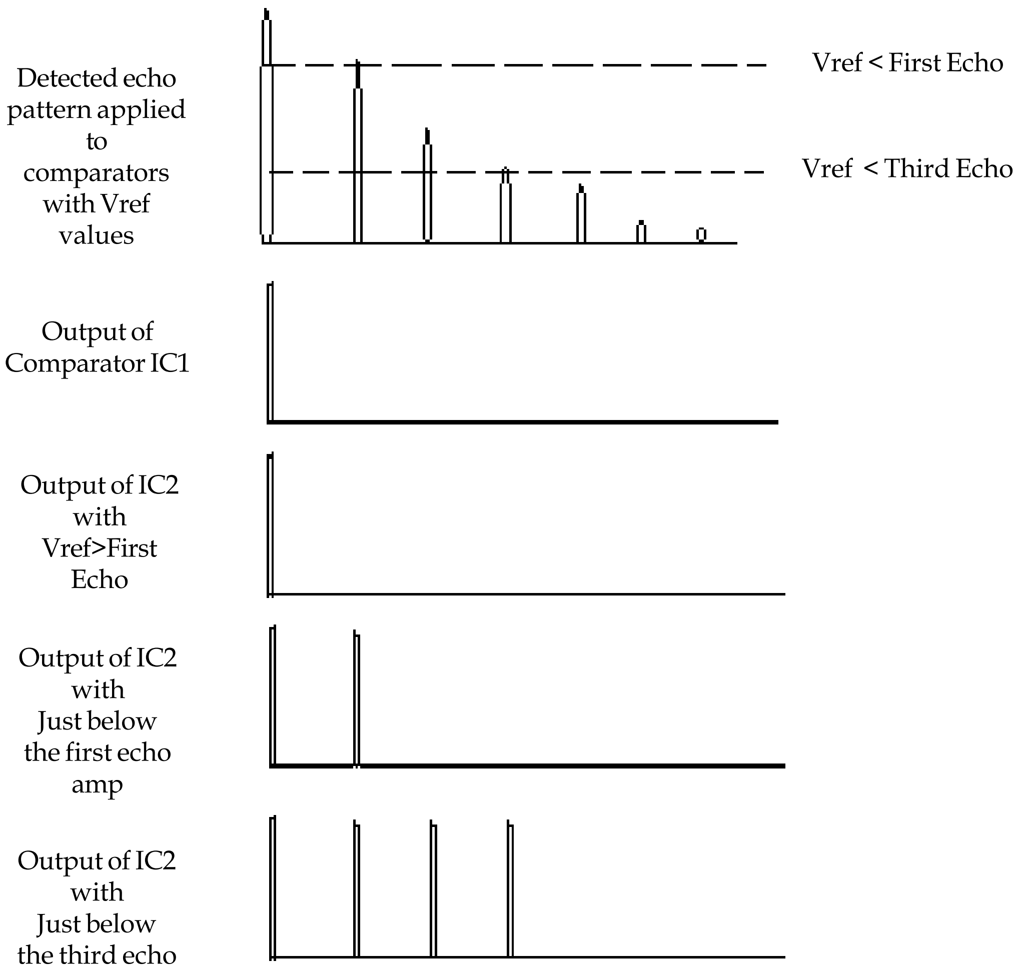

Fig. 4. Timing diagram of comparator circuit

Now, the ultrasonic attenuation (α) is calculated using following formula [23]

$$\alpha = \frac{20}{2l}\log_{10}\left(R_{avg}\right) \tag{2}$$

Where, α is the ultrasonic attenuation coefficient in dB/cm and l is sample length. Sometimes, the attenuation factor is expressed in Nepers per centimeter.

$$1\ {}^{Nep}/_{cm} = 8.686\ {}^{dB}/_{cm} \tag{3}$$

A control program has been written in "C", to display the following information on the user screen

- Amplitudes of echoes with echo number (The designed hardware has facility to detect and measure amplitudes of seven echoes, sufficient for estimation of attenuation).
- Ultrasonic attenuation coefficient in neper. m^{-1} s^2

3. Results and Discussions

The precision measurement of the instrument was carried out on distilled water. Attenuation measurement in distilled water over a time period of about four hours is shown in Fig. 5. The sample was maintained at the desired temperature using thermostat U10. The measurement has been carried out at 34ºC for 18 readings. The standard deviation over this period was found to be 0.0033 dB/cm.

The overall attenuation (loss) consists of two

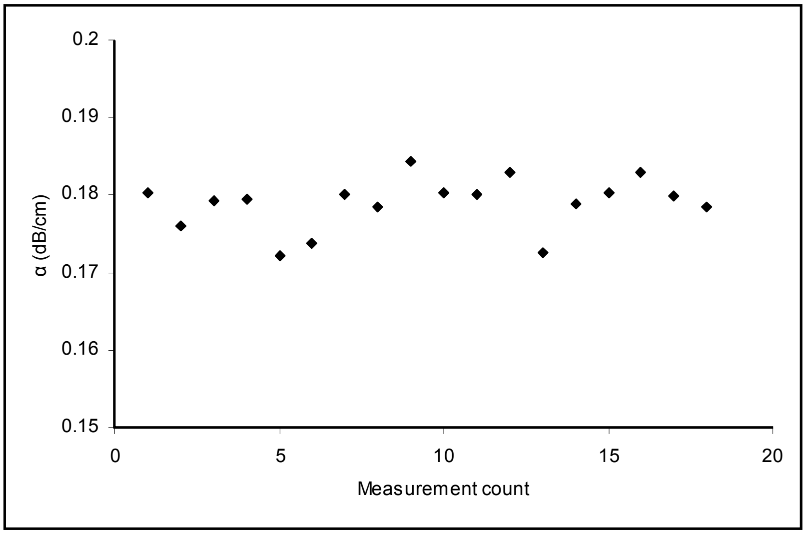

Fig. 5. Attenuation at 10 MHz for distilled water over 4 hours

components; "losses in sample" and "transducer loss". Transducer losses include loss in converting the electrical energy into acoustic energy, loss due to reflection at two surfaces (between transducer and sample) and the loss in converting the acoustic energy back into the electrical signal [3]. Subtracting the transducer loss from the overall loss gives the attenuation in sample. Dukhin et al explained these losses in their work; and observed that a transducer used at multiple frequencies has maximum conversion efficiency at its resonance frequency. Inherently such transducers have loss maxima at even multiples of their resonant frequency and loss minima at odd multiples.

We have measured an absolute attenuation in doubled distilled water stabilized at 34ºC. Transducer loss has been estimated using attenuation value taken from standard literature [23, 24]. It is obvious that the transducer loss which is even less than the attenuation of water (less attenuating liquid), will be significant in the study of low attenuating liquids. This loss will be of less significance for measurement in higher attenuating samples. The technique was further verified on some standard liquids and is shown in Fig. 6, Fig. 7 and Fig. 8.

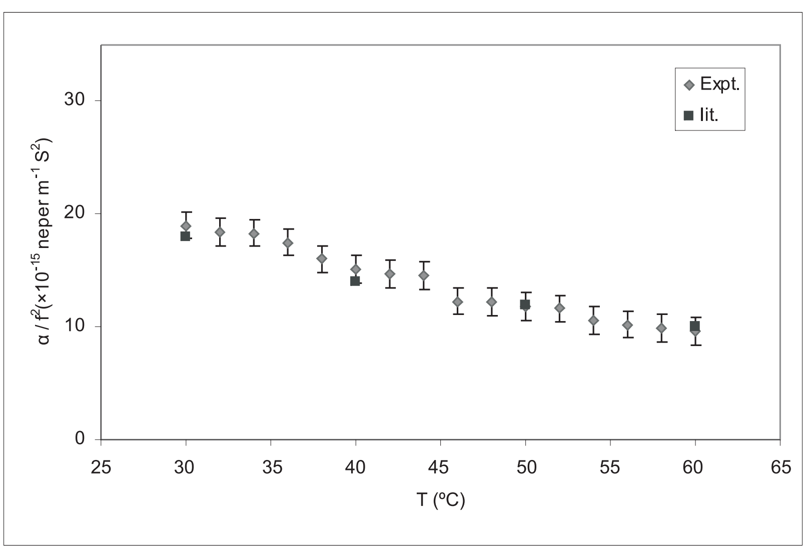

Fig 6. Temperature dependence of attenuation coefficient (α/f^2) in water

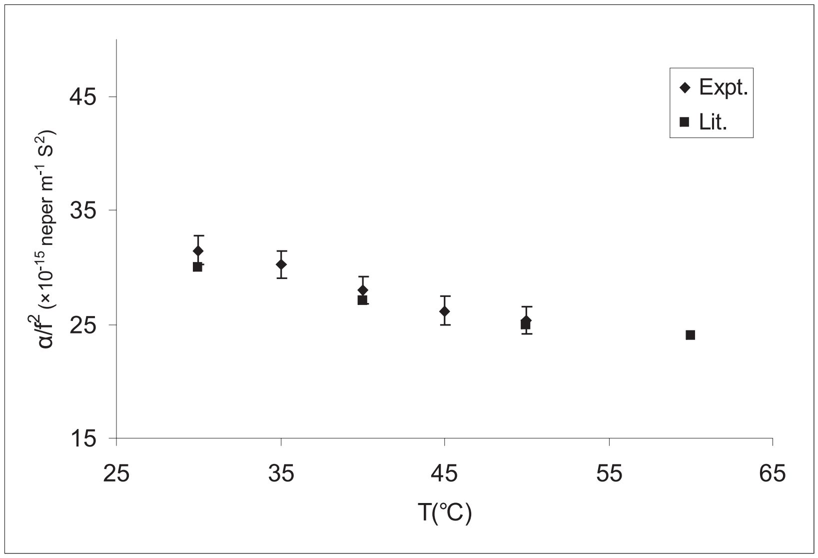

Fig. 7. Temperature dependence of attenuation coefficient (α/f^2) in methyl alcohol

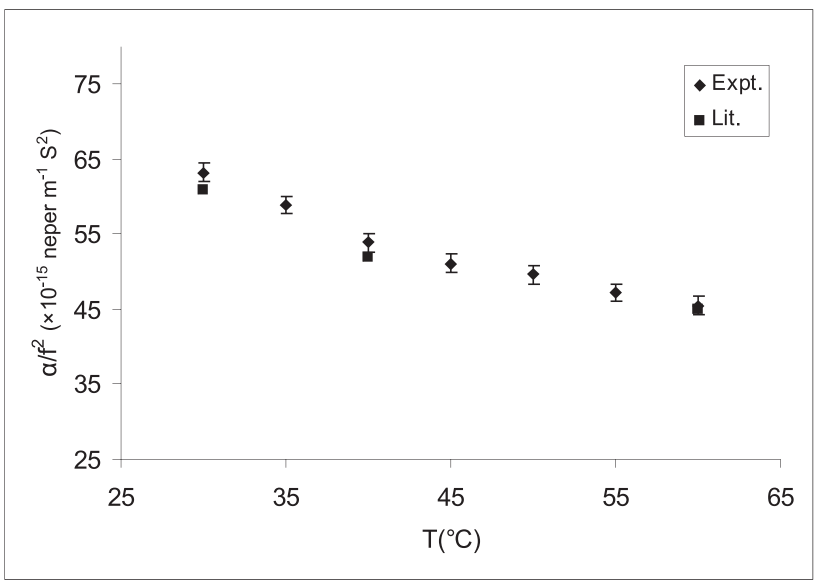

Fig. 8. Temperature dependence of attenuation coefficient (α/f^2) in n- propanol

The designed technique has been implemented and tested for 10 MHz pulser-receiver. No doubt, the technique can also be used for variable frequencies by just replacing the pulser-receiver module. The echo amplitude measurement resolution has been set at 4mV by using a 10 bit DAC. This resolution can further be improved to 1mV by using a 12 bit DAC. Furthermore, the technique developed can only be applied for an exponentially decaying echo pattern hence; it is not applicable for the detection of flaw in solids.

Acknowledgment

The authors are grateful to Mrs. A. D. Sakhare, Head, Department of Electronics, R.S.T.M. Nagpur University, Nagpur, for providing the neccesary infrastructure to carry out the work and to Dr. M. N. Ghoshal for his interest in the work. One of the authors

(SJS) is grateful to the University Grants Commission (UGC) New Delhi, India, for the financial assistance to carry out the above work.

References

[1] P. Vigoureux, Ultrasonics, Chapman & Hall Ltd, London, (1952) 99-115.

[2] J. Blitz, Fundamentals of Ultrasonic, Butterworth, (1963) 1-9.

[3] A.S. Dukhin and P.J. Goetz, Ultrasound for Characterizing Colloids: Particle Sizing, Zeta Potential, Rheology, Elsevier, London, (2002) 75-86.

[4] P. Papadakis, Physical Acoustics, Academic Press, New York, (1976) 323-328.

[5] L. Pathak, N. Murali and S. Usha rani, Rev. Sci. Instrum., **54** (1983) 482-485.

[6] J.R. Pellam and J.K. Galt, J. Chem. Phys., **14** (1946) 608.

[7] J.M.M. Pinkerton, Nature, **160** (1947) 128.

[8] H.J. McSkimin, J..Acoust . Soc. Am., 33 (1961) 12.

[9] H.J. McSkimin and P. Andreath, J. Acoust. Soc. Am., **34** (1962) 609.

[10] H.J. McSkimin, J. Acoust . Soc. Am., **29** (1957) 1185.

[11] A.J. Barlow and P. Yazgan, Brit. J. Appl. Phys., **17** (1968) 807.

[12] M. Badev, Acoustica, **20** (1968) 41.

[13] User Manual, Tektronix DSO, TDS 2014, (2006).

[14] A.K. Singh, Industrial Instrumentation and Control, Tata Mcgraw Hill New Delhi (India), (2005) 551-582.

[15] I. Koller, R. Pintelon and J. Schoukens, IEEE Instrumentation and Measurement Magazine, **19** (2003).

[16] I. Koller, R. Pintelon, J. Schoukens and G. Simon, IEEE Instrumentation and Measurement Magazine, **27** (2003).

[17] A. Sachenko, V. Kochan and V. Turchenko, IEEE Instrumentation and Measurement Magazine, **6** (2003) 34-40.

[18] S. Gupta and J.P. Gupta, PC Interfacing for Data Acquisition and Process Control, Copy Right to Instrument Society of America, N.C., (1994) 129-139.

[19] Joseph Babu, Real Time Personal Computing for Data Acquisition and Control, Printice Hall, USA (1989).

[20] A.P. Malvino and D.P. Leach, Digital Principles and Applications, Tata Mcgraw Hill, New Delhi (India) (1991) 279-291.

[21] I.M. Gottlieb, Solid State High Frequency Power, Reston Publishing Company Inc, Reston, Virginia, (1982) 67-74.

[22] S. Rajagopalan, S.J. Sharma and P.K. Dubey, Rev. Sci. Instrum., **78** (2007) 085104.

[23] T.A. Litovitz and K.F. Herzfeld, Absorption and Dispersion of Ultrasonic Waves, Aacademic Press, (1959).

[24] http://www.kayelaby.npl.co.uk