Development and Simulation of Ultrasonic System

Y. B. Gandole

Department of Electronics, Adarsha Science J.B.Arts and Birla Commerce Mahavidyalaya Dhamangaon Rly-444709 -India

Abstract: *Instrumentation for ultrasonic velocity and attenuation measurements in liquids and solids is described. 5 MHz pulse generator is assembled using CMOS integrated circuits (4011, 7414, 74121, and 4010), having pulse width 2 microseconds to 60 microseconds. The wideband receiver is developed using Wideband Low Distortion, High Gain Operational Amplifier (OPA 643). The gain and bandwidth of the receiver are 50 dB and 10 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.*

Keywords: *Instrumentation, Ultrasonic ,Pulse generator, Receiver, Simulation*

I.   Introduction

Measurement of sound velocity and attenuation can provide considerable information about the physical properties of solids and liquids. Ultrasonic has been used as means of investigation in physical research. Modes of its propagation can yield information on the properties of the medium and on its structures. 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 elastic moduli, Poisson's ratio, residual stresses, texture, porosity and characterization of secondary phases in microstructure etc. [Green 1981, Bharadwaj 1986, Jayakumar et al 1990]. Ultrasonic methods are now widely used for many purposes: academic, industrial, and medical. For many applications, simple detection suffices to determine the time intervals between pulses. For other uses, such as the determination of material constants, accurate surface displacement waveform measurements may be needed. A variety of systems [Scruby et al 1990, O'Keefe et al 1995 and Monchalin 1986] have been shown to yield highly accurate waveform information and to have high sensitivity, even under adverse ambient conditions. Because they typically involve elaborate apparatus: Confocal Fabry-Perot interferometers [Shan et al 1995 and Monchalin 1985], photorefractive materials [Klein et al 1999] high power laser generators and high power laser detectors, these systems can be very expensive, and can themselves add hazards to the working environment. Recently various pulse methods are 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 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 [Agnihotri et al 1988, Rao et al 1993]. As broader is the range of areas involved in ultrasonic measurement, as more essential becomes the question of universal equipment for generating and acquiring the ultrasonic data. This paper deals with instrumentation design and measurements for proposed ultrasonic system.

II.   Instrumentation

The basic conceptual model for the ultrasonic measurement system for solids and liquids is shown in figure 1. The ultrasonic transducer is excited by generation of electrical pulse and transmits the ultrasonic pulse to the media under investigation. The ultrasonic pulse travels in the material reflected, refracted, scattered or transmitted through its in- homogeneities. The affected signal is picked by receiving transducer and is converted to the electrical signal. This signal is then amplified, filtered and converted to the digital form using digitizer. After the raw data has been acquired from the pulser-receiver by the digitizer, but before a velocity and attenuation estimate can be made, a significant amount of signal processing must be done for a successful measurement to occur. There is some basic processing that is needed for all sets of data.
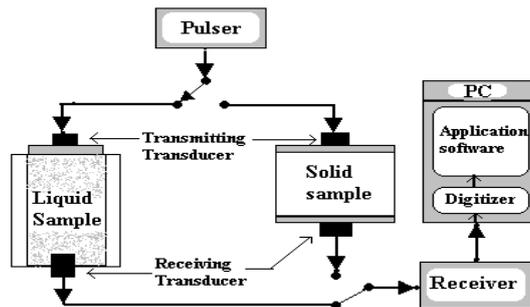
Fig 1: Conceptual model for the ultrasonic velocity and attenuation measurement system.

Pulse Generator

Figure 2 shows the circuit diagram of 5MHz pulse generator. Using CMOS integrated circuit 4011 and a 5 MHz quartz crystal, assembles a crystal oscillator circuit. 1 KHz clock pulse is generated using Hex Schmitt-Trigger Inverters (7414), The 7414 is a high-speed Si-gate CMOS device and is pin compatible with Low-power Schottky TTL (LSTTL). 7414 provides six inverting buffers with Schmitt-trigger action.
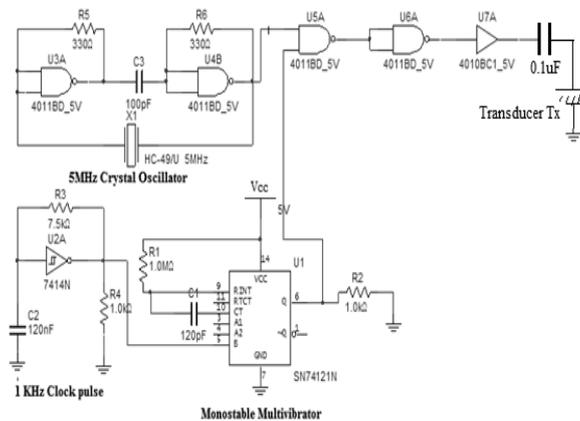
Fig. 2 : Pulse Generator

It is capable of transforming slowly changing input signals into sharply defined, jitter-free output signals 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 120 pF between pin 11 and 10 of 74121. The output of 74121 and 5MHz frequency signal is applied to the AND gate. The resulting pulse is then fed to 4010 (Hex buffer) The amplitude of output pulse uses **5** V peak to peak; which is given to sender transducer (Tx). Designing a 1KHz oscillator needs the following formula (1) for calculation of frequency

$$F = 1/1.2RC \tag{1}$$

And for the monostable multivibrator we need the following formula (2) for calculating the pulse width

$$T = 0.33(RC) \tag{2}$$

Designing a crystal oscillator using gates instead of buying a pre−packaged device that includes all the active components provides the benefits as: Save Money and • Control the Parameters that are Critical to the Design. The resulting waveforms are shown in figure (5a-d)

Receiver

When narrow rectangular high frequency pulse passes through the sample it gets modified due to unequal attenuation of different harmonics of the pulse in the sample. The receiver used for reception and detection of such signals must be capable of giving as faithful reproduction of the signal as possible. It must have good amplitude linearity over a wide dynamic range [Truel et al 1969]. Usually, preamplifier is placed closer to the transducer than the rest of the system, for having low noise level and after preamplifying the signal, 6-20dB signal can be sent further [Armitage et al 1995]. Amplifier has to filter the noise at the frequencies, which are definitely out of employed frequency range. When the input of the receiver is matched to the transducer in order to optimize signal-to-noise ratio, the actual noise is considerably greater due to the contribution from the effective input resistance, and the dynamic range is reduced. Therefore, in order to have maximum dynamic range some mismatch has to be accepted [Soitkar et al 1980]. To preserve the pulse shape the receiver has to have a large enough bandwidth. When the bandwidth is small, the signal-to-noise ratio

improves, but the pulse shape is distorted [Matchenbacher et al 1973]. To obtain accurate positional resolution a compromise has to be made between signal-to-noise ratio and pulse shape. In the present system , the transmitted pulse of 20 V is used, which gives a received signal of a few millivolts. Considering the threshold voltage of 700 mV of a diode in the detector stage, the receiver input voltage has to be amplified to a magnitude greater than this value. This requires a large gain for the receiver. To overcome this problem, wideband zero crossing detector is used in the present receiver design.

The circuit diagram of wideband receiver is shown in figure 3. An amplifier consists of single stage, which is assembled by using transistor Q_1 and Q_2 (BF240). The output of single stage amplifier is again amplified with the help of another amplifier using IC OPA 643. The OPA643 provides a level of speed and dynamic range previously unattainable in a monolithic op amp. Using a de-compensated voltage feedback architecture with two internal gain stages, the OPA643 achieves exceptionally low harmonic distortion over a wide frequency range. The "classic" differential input provides all the familiar benefits of precision op amps, such as bias current cancellation and very low inverting current noise compared with wideband current feedback op amps. High slew rate and open-loop gain, along with low input noise and high output current . drive make the OPA643 ideal for very high dynamic range requirements. The high gain bandwidth product for the gain ☐ ☐ 3 stable OPA643 makes it particularly suitable for wideband trans impedance amplifiers and moderate gain IF amplifier applications. External compensation techniques may be used to apply the OPA643 at low gains giving exceptionally low distortion and frequency response flatness. Where unity gain stability with comparable distortion performance is required, consider the OPA642.

The overall characteristics of amplifier are as: gain is 40 dB, bandwidth is 10 MHz, input impedance is 10.5 kΩ and low noise.
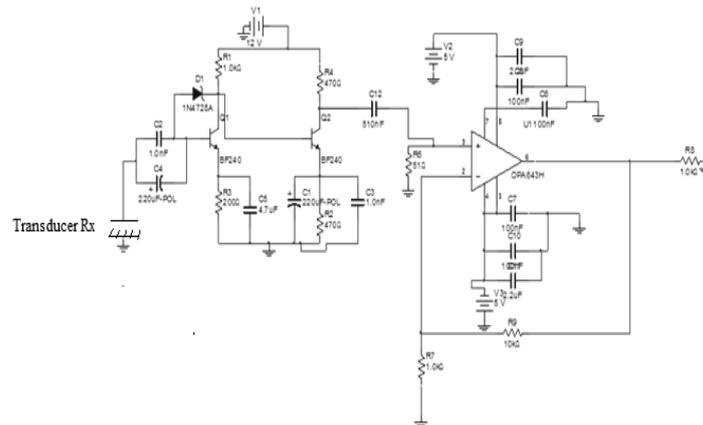
Fig. 3 : Receiver circuit

III. System Simulation

The ability to simulate both piezoelectric transducer and electronics together renders possible effective optimizations at system level, i.e. minimizing size, cost and power consumption. In this paper the simulation of a combined electronics and ultrasonic piezoelectric transducer is explored. The environment used is compatible with the electronic simulation tool Multisim. Improvement and verification of existing Multisim models for ultrasonic system is applied in the design of integrated analog electronics for an ultrasonic measurement system. Ultimately simulations are used to predict the response of a system without having to build it. From management point of view, it is done to save time and money as preliminary design have flaws. It is not feasible to have a scaled model; a mathematical model should lead to the right direction. In the case of ultrasound, a mathematical model makes much more sense. The simulation circuit is shown in fig.4. The piezoelectric phenomena are modeled using controlled voltage and current sources [Leach 1994]. The measuring cell is modeled using lossy transmission line. The characteristics of these lossy transmission lines can be given by following formulae

$$R = 2\rho c A \alpha_v$$

$$G = \frac{2\alpha_{tc}}{\rho c A} \qquad\qquad (4)$$

$$L = A \cdot \rho \qquad\qquad (5)$$

$$C = \frac{1}{A\rho c^2} \qquad\qquad (6)$$
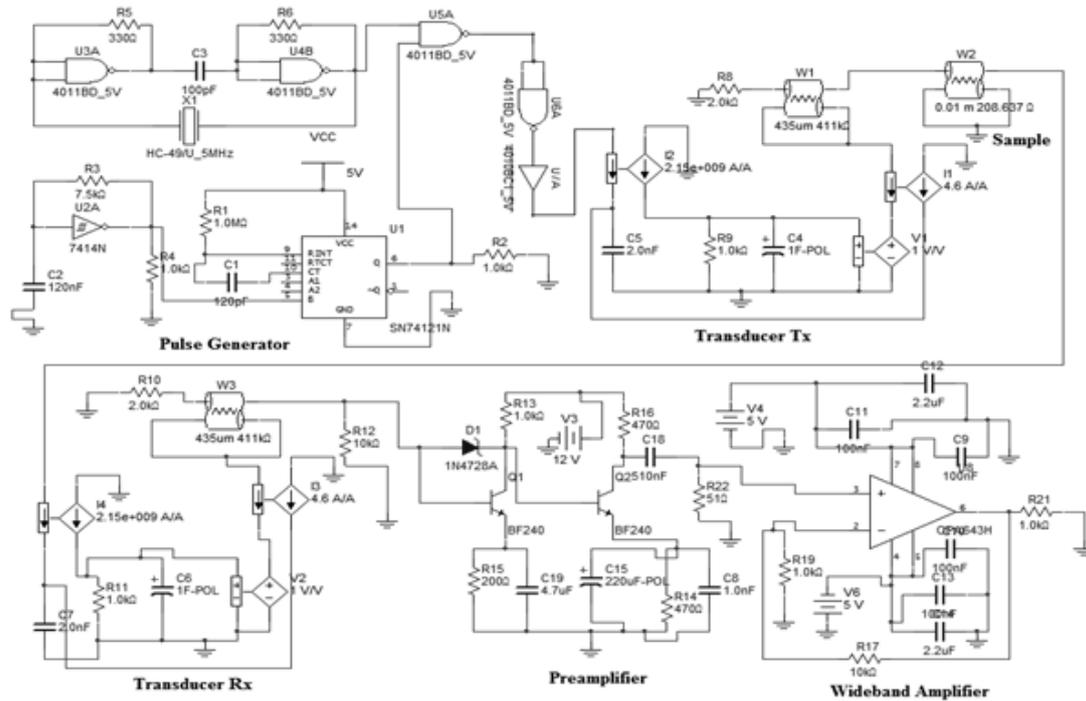
Fig.4 : Simulation circuit

IV. Results And Discussion

The system is checked by measuring the ultrasonic velocity and attenuation in distilled water 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 (a to d).

Figures 6 (a to e) show the received signals for distilled water. The distance between transmitting transducer (Tx) and receiving transducer (Rx) is 1 cm and 5 cm. Table 1 shows the comparison between the literature values and measured values of ultrasonic velocity and attenuation for the liquid and solid samples.

(a)

(b)

(c)

(d)
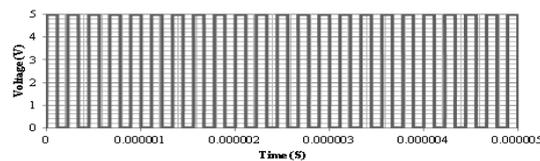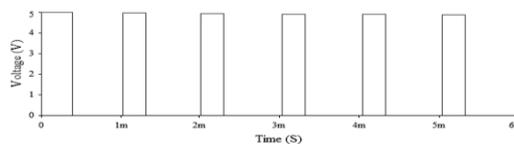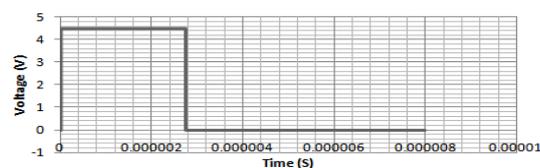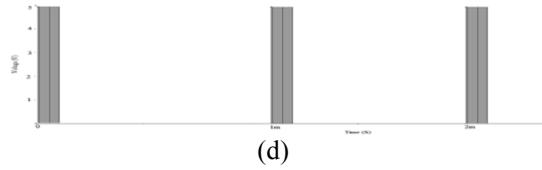
Figure 5. (a) Signal at the output of U4B (5MHz), (b) Signal at the output of U2A (7414) (1KHz), (c) 2.5 μs pulse at pin No. 6 of U1 (74121), (d) Signal at the output of U7A (4010BC)

(a)

(b)

(c)

(d)

(e)
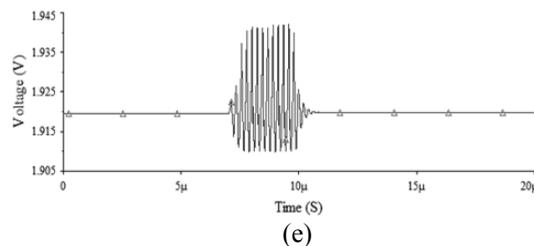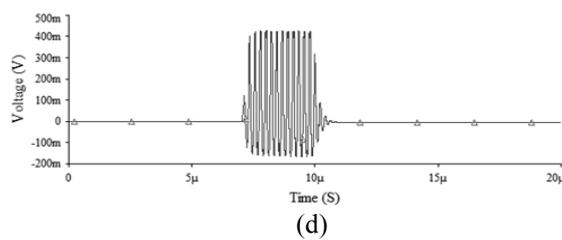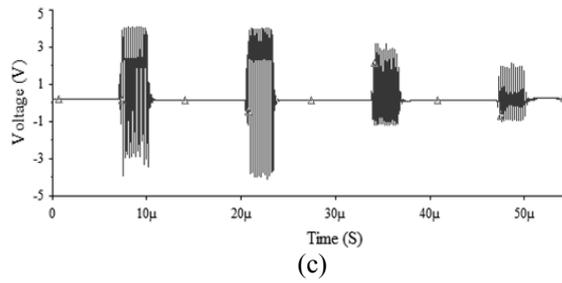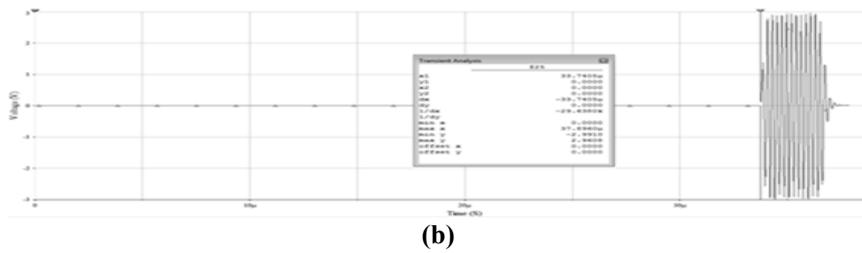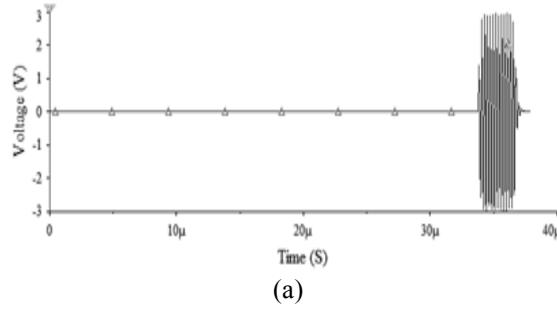
Fig. 6 (a) Complete transient received by 5 MHz transducer at 25°C in Distilled water at 25°C for d=0.05m (b) Simulated transient response received by 5 MHz transducer at 25°C in Distilled water at 25°C for d=0.05m (c) Complete transient received at output of OPA643 by 5 MHz transducer at 25°C in Distilled water at 25°C for d=0.01m (d) Complete transient received at output of Preamplifier by 5 MHz

transducer at 25°C in Distilled water at 25°C for d=0.01m (e) Complete transient received at output 5 MHz transducer (Rx) at 25°C in Distilled water at 25°C for d=0.01m

Table 1: Comparison of ultrasonic velocities in liquid and solid samples at 25°C.

S.No.	Sample	Simulated velocity (m/s)	Literature value	Reference
1	Distilled water	1497.448	1497	Weast et al 1964
2	Ethanol	1207.498	1207	Weast et al 1964
3	Methanol	1103.712	1103	Weast et al 1964
4	Acetone	1174.412	1174	Schaaff 1967
5	Benzene	1310.567	1310	Weast et al 1964
6	Aluminium	5143.895	5140	Podesta 2002
7	Steel	5870.132	5874	Kaye et al 1995
8	Polyethelene	2558.963	2560.20	Yawale et al 1995
9	Polystyrene	2348.719	2350	Podesta 2002
10	Copper	4750.463	4756	Kaye et al 1995

References

[1] Agnihotri P. K., Adgaonkar C. S., Research and Industry, **33**, 1988, 139.
[2] Bharadwaj M. C., Advanced Ceramic Materials, **1** (4), 1986, 311-324.
[3] Green Jr R.E., Effect of metallic microstructure on ultrasonic attenuation in NDE: Material Characterization and Reliability Strategies, O. Buckand S. M. Wolf Eds., Metallurgical Soc. of AIME, USA, 1981, 115-132.
[4] Jaykumar T., Raj Baldev, Willems H. and Arnold W., Proc. Review of progress in QNDE, edited by D.O. Thompson and Chimenti, Plenum Press, New York. **10**, 1990, 1693-1700.
[5] Klein M. B., Bacher G. D., Grunnet-Jepsen A., Wright D., and Moerner W. E., Optics Commun. **162**, 1999,79-84.
[6] Leach W.M., IEEE Trans. Ultrason, Ferroelect., Freq. Contr., **41**, 1994, 60-66.
      Matchenbacher C.D. & Fitchen F.C., Low Noise Electronic Design, John Wiley and Sons. New York, 1973, 230-231.
[7] Monchalin J. P., IEEE Trans. On Ultraso., Ferroelect., and Freq. Control, **33** (5), 1986 , 485-499.
[8] Monchalin J. P., Appl. Phys. Lett . , **47**, 1985,14-16.
[9] O'Keefe C. V. and Palmer C. H., Open Beam Interferometric Measurement of Ultrasound in Nondestructive Testing Handbook, 2nd ed., **9**, Special Nondestructive Testing Methods, 1995 , 160-190.
[10] Podesta Michael De, Understanding the Properties of Matter, 2nd ed. Taylor and Francis Inc. New York, 2002, 194.
[11] Kaye G.W.C. and Laby T.H., Tables of Physical and chemical Constants, 16th ed. Harlow, UK: Longman Group Ltd., 1995, 94-111.
[12] Rao B.P.C., Jayakumar T, Bhattacharya D.K. and Raj Baldev, J. Pure Appl. Ultraso., India, **15**, 1993, 53-59.
[13] Armitage A.D. and Scales N.R., Sensors & Actuators A: Physical, **47**, 1995, 542-546.
[13] Schaaff W., Numerical data and functional relationalships in Science and Technology, New Series Group II: Atomic and Molecular Physics, Vol.**5**: Molecular Acoustics, Eds. Hellwege K.H., New York, 1967, 51-52.
[14] Scruby C. B. and Drain L. E., Laser Ultrasonics: Techniques and Applications, Adam Hilger Publ., 1990, 112.
[15] Shan Q., Chen C. M., and Dewhurst R. J., Meas. Sci. Technol. **6**, 1995, 921-928.
[16] Soitkar V.S., Sunnapwar K.P., and Navaneet G.N., Indian J. Tech., **18**, 1980, 469.
[17] Truel R., Elbaum C., and Chick B.B., Ultrasonic methods in Solid State Physics, Academic press, New York, 1969, 136-138.
[18] Weast R.C. (ed.) Handbook of Chemistry and Physics, 45th ed. Chemical Rubber Co., Cleveland Ohio, 1964, E-28.
[19] Yawale S.P. and Pakade S.V., Ind. J. Pure Appl. Phys., **33**, 1995, 638-642.