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Development of sweep frequency ultrasonic interferometer for high precision velocity measurement in liquids

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ABSTRACT

An ultrasonic interferometer with variable separation between the transducer and reflector is widely used for the measurement of ultrasonic propagation velocity in liquids. The inherent limitation of such an interferometer is due to the mechanical movement of its reflector for ultrasonic wavelength measurement in a liquid medium. It is observed that the ultrasonic velocity measurement precision is adversely affected at higher frequencies compared to lower ones. For instance, in our experimentation, a standard deviation of ±21.5 m/s (±1.43%) was obtained for velocity measurement at 1.84 MHz with the consideration of two consecutive maxima, which increases drastically to ±76.8 m/s (±5.12%) at 9.4 MHz. These measurements can significantly be improved by considering many maxima and averaging for wavelength estimation. However, it still requires design attention and improvement, particularly for higher frequencies. In this article, a sweep-frequency based ultrasonic interferometer design with a fixed separation for liquid characterization is proposed and described. This technique overcomes the limitations of mechanical movement systems and also provides a better and uniform precision for lower as well as higher frequencies. The functionality of the developed sweep frequency method was tested in water, carbon tetrachloride, ethylene glycol, and glycerol, which shows good agreement with literature values. The velocity measurement in double distilled water by the developed technique at 1 Hz sweep resolution has shown an improved standard deviation of ±0.74 m/s (±0.05%) at 9.4 MHz.

I. INTRODUCTION

Ultrasonic velocity is an important parameter used for liquid characterization and has numerous applications. The physico-acoustic parameters of liquid samples are derived from the ultrasonic velocity of liquids.[1–4] Various ultrasonic techniques for the measurement of ultrasonic propagation velocity in liquids include resonance reverberation, pulse-echo, coherence phase detection, and ultrasonic interferometer. Out of these, the ultrasonic interferometer technique is the most widely used due to its simplicity, low cost, and ability to work with a relatively smaller sample volume.[5–7] Generally, for velocity measurements, two types of ultrasonic liquid cell arrangements are used: double transducers and single transducers. Among these, the single transducer cell is widely used because of its inherent advantages, with the same transducer being used as a transmitter as well as a receiver. The liquid sample holders are generally fixed transducer types, and a movable reflector is preferred to change the separation between them.[8–10] There are many situations in which it is inconvenient and undesirable to measure ultrasonic velocity by varying the reflector separation in the sample holder. Another reason for not using the variable separation is the limitation of the mechanical movement system. The propagation velocity measurement in a variable path ultrasonic interferometer is limited due to its mechanical movement errors. The mechanical movement-based interferometers for the detection of maxima/minima are influenced by the non-linearity, backlash, and accuracy of the distance measurement.[11] Even with the best detection electronics for the maxima, the overall measurement is limited by the micrometer resolution. The simple solution to this is to have a sample holder with a fixed separation between the transducer and reflector. The literature in the field reveals that not many efforts have been made for the measurement of ultrasonic velocity using a variable frequency approach, particularly in liquid samples. A twin direct digital synthesizer (DDS) based system was used as a sweep frequency, in which one DDS was used as a transmitter and the other was used as a receiver (Refs. 12 and 13). The major drawback of this system was twin DDS and its complexity to generate the same amplitude, frequency, and timing synchronization of the field-programmable gate array (FPGA) module with DDS. In another study, a complex instrumentation system with a digital synthesizer and analyzer board with heterodyne mixing technique was described.[14] In frequency sweep operation, the two-transducer method has the limitation of not exactly matching the same bandwidth. It is difficult to detect signals with narrow bandwidth transducers. Heterodyne mixing in RF detection with the effect of coaxial cable within 3 dB bandwidth due to the generation of intermediate frequency ultimately affects detection with respect to sweep operation. Obviously, for small bandwidth operation, the single transducer method is the best choice due to the same transducer working as a transmitter as well as a receiver.

In this article, the development of a sweep frequency ultrasonic interferometer with a fixed separation type sample holder using only one transducer is described. The personal computer-based system has facilities to sweep frequencies with a 1 Hz step resolution. It was experimentally verified that the proposed velocity measurement technique significantly improves the precision of ultrasonic velocity measurement.

II. CONVENTIONAL VARIABLE SEPARATION TYPE ULTRASONIC INTERFEROMETER

The conventional ultrasonic interferometers use a movable reflector to change the transducer to reflector separation and measure ultrasonic propagation velocity by the following relation:

$$c = f \cdot \lambda, \tag{1}$$

where c is the propagation velocity of ultrasound in the liquid sample, f is the ultrasonic excitation frequency, and λ is the wavelength in the liquid medium measured by detecting the consecutive antinodes as half-λ.

The mechanical limitations of variable reflector type interferometers can be found in the literature.[11] One of the critical limitations of such a system is its non-suitability at relatively higher frequencies as the wavelength becomes shorter. This is particularly true because the least count of the micrometer becomes a significant factor. Figure 1 shows the effect of micrometer resolution used for reflector movement on water velocity as a function of frequency at 20 °C. The least count of the conventional ultrasonic interferometer used was 10 μm. So, when the frequency goes high, it is very difficult to measure the wavelength of the wave inside the liquid sample. Furthermore, as the number of antinodes under consideration is small, the error associated with the measurement of ultrasonic velocity increases. Therefore, for a better precision, it is desirable to consider a higher number of antinodes.

III. FIXED SEPARATION TYPE SWEEP FREQUENCY ULTRASONIC INTERFEROMETER

The developed system of fixed separation ultrasonic interferometers is different from that of variable path interferometers. It has a liquid cell with a fixed path, a fine programmable variable frequency excitation source, and a detection circuit. The sample holder has a transducer fixed at the bottom of the cell and, at the other end, a fixed reflector to reflect the ultrasonic signal back to the transducer. The same transducer acts as a transmitter as well as a receiver.

The amplitude of ultrasonic wave propagation in a liquid medium with time (t) is given by[15]

$$v(x,t) = V_o \exp i(kx - \omega t), \tag{2}$$

where V_o is the excitation amplitude, x is the distance of the wave propagated in time t, k is the wave vector, and ω is the angular frequency. Generally, the attenuation component of a wave vector ($k = \frac{\omega \cdot d}{c} + \mathrm{i}\alpha$) is dependent on frequency. From Eq. (2), assuming that the attenuation component (α) is constant with extremely low

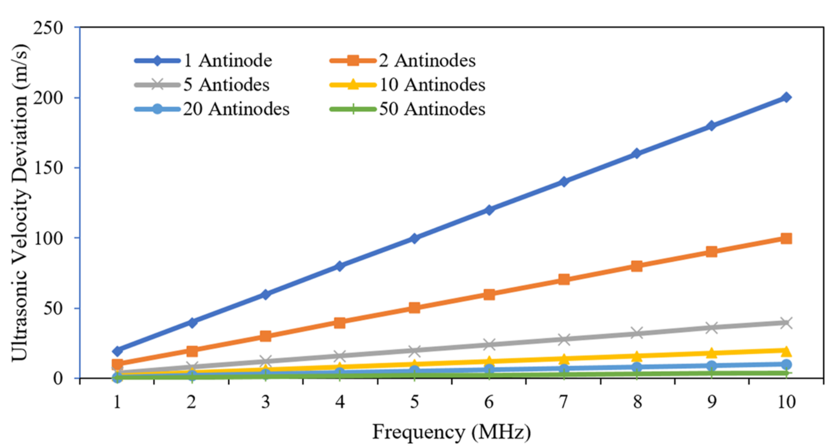

FIG. 1. Deviation in ultrasonic velocity measurement with frequency due to the micrometer resolution used in conventional variable path ultrasonic interferometers.

variation, the frequency sweep is very small during velocity measurement. In this technique, the separation (d) between the transducer and reflector is fixed (replacing x with d), and the frequency is swept within the operating range (3 dB bandwidth) of the transducer. Due to the interference of reflected and transmitted waves, the positions of nodes and antinodes (maxima) are shifted at different excitation frequencies.

From Eq. (1), the amplitude at the angular frequency (ω) is

$$V(\omega) = V_o e^{i\left(\frac{\omega \cdot d}{c}\right)}. \tag{3}$$

The received signal is a periodic function of $\frac{\omega \cdot d}{c}$ as

$$V(\omega) = V_o\left[\cos\left(\frac{\omega \cdot d}{c}\right) + i\,\sin\left(\frac{\omega \cdot d}{c}\right)\right]. \tag{4}$$

Therefore, when antinodes (peaks) occur, the condition is[14]

$$\frac{2d f_n}{C} = n, \tag{5}$$

where f_n is the excitation frequency of the nth maxima. n is the number of wave counts in the sample holder having separation d. It is obvious that the maxima occur when n is an integer. Here, factor 2 is due to the double path of ultrasound traveled to reach back to the transducer.

Now, consider that the liquid sample is non-dispersive in nature, at least for the small change in ultrasonic frequency with the 3 dB bandwidth of the transducer. So, the ultrasonic velocity c remains constant. Similarly, for the immediate next maxima (n + 1)th, while ultrasonic frequency increased, it may further be given by

$$\frac{2d f_{n+1}}{C} = n + 1. \tag{6}$$

Now, from Eqs. (5) and (6), we have

$$\frac{2d f_{n+1}}{C} - \frac{2d f_n}{C} = 1. \tag{7}$$

Simplifying the equation further, the ultrasonic propagation velocity through the liquid sample can be calculated by

$$c = 2d\Delta f. \tag{8}$$

Equation (8) indicates that the measured ultrasonic propagation velocity by the sweep frequency approach is directly proportional to Δf ($f_{n+1} - f_n$) and separation d. It is clear that the frequency deviation would be large for the smaller value of d, which, in turn, defines the liquid sample volume. It needs to be considered that the frequency sweep during the measurement is well within the transducer's bandwidth and should only cover a small part of it to achieve almost uniform sensitivity. Figure 2 shows the impedance response of the ultrasonic transducer used in the experimentation.[16] The impedance response was acquired using an impedance analyzer (Agilent: E4991A). From the figure, it is observed that the transducer has a fundamental resonant frequency of 1.745 MHz with significant anti-resonance at 1.885 MHz. It is also noticeable that the transducer not only is useful for the fundamental frequency (1.7 MHz) but may also be utilized for third and fifth harmonics. The impedance response indicates the usability of the transducer for a wider bandwidth of 140 kHz at the fundamental frequency, along with the above harmonics.

Now, before going into the actual design of the liquid cell based on the bandwidth of the transducer, different values of transducer and target separations were used to analyze the best suitable frequency shift. As Δf depends on the value of ultrasonic velocity in liquid for a particular path length d, the cell design was optimized for distance in such a way that it covers the entire range of ultrasonic velocity of liquids and Δf lies well within the bandwidth of the transducer.

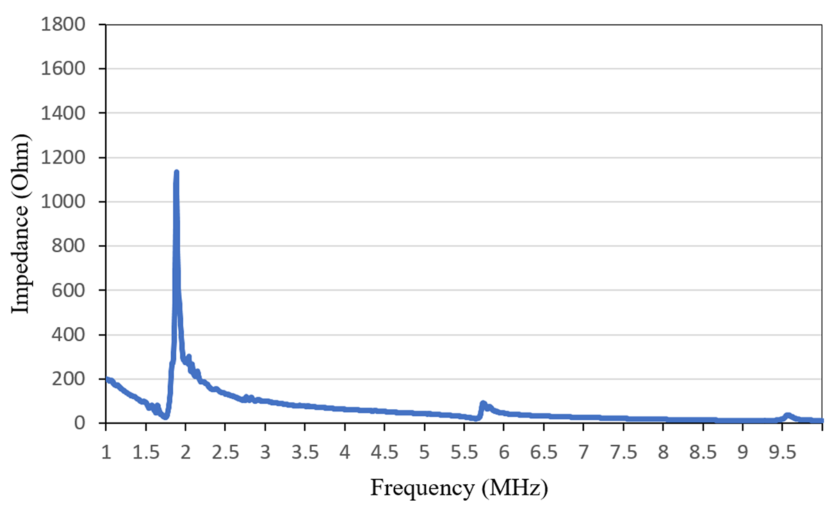

FIG. 2. Impedance response of an ultrasonic transducer used acquired using an impedance analyzer.

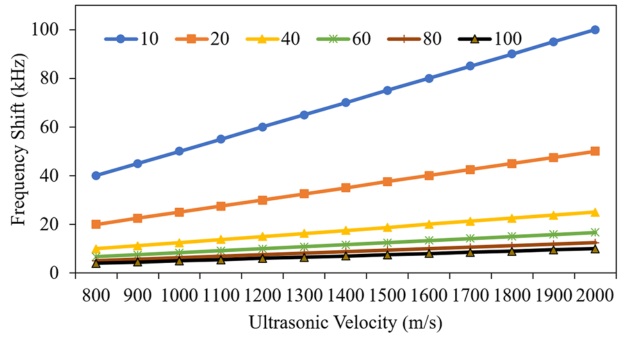

FIG. 3. Frequency shift for the entire range of liquid velocity at different values of separation (10–100 mm) between the transducer and reflector.

The frequency shift remains the same for all the excitation frequencies, whether they are fundamental or harmonics, provided that the liquid under study is non-dispersive. Figure 3 shows Δf within the range of liquid velocity at different values of the separation between the transducer and reflector. The separation was varied between 10 and 100 mm to analyze the frequency shift in order to cover the entire range of liquids for ultrasonic velocity measurement. It was observed that the transducer–reflector separation of 40 mm requires a frequency sweep of 15 kHz between two consecutive maxima, and the frequency sweep obviously doubles at 20 mm separation. Therefore, the distance of 36 mm separation was chosen to cover the entire velocity range of liquids (carbon tetrachloride to glycerol), along with minimization of the diffraction effect, and provide sufficient change in frequency for detection.

A. Fixed separation ultrasonic liquid cell design

When designing an ultrasonic liquid cell, the major considerations that need to be taken into account are the size of the piezoelectric disk, the diameter of the reflector, and the volume of the liquid sample. Generally, brass or stainless steel is preferred during the development of a liquid sample holder due to its high reflection coefficient at the liquid interface. Herein, brass material was used for the entire cell design. There are two hollow cylinders used to form the outer jacket, and the inner cylinder holds the sample as shown in Fig. 4. The outer jacket has an inlet and outlet for the circulation of water and temperature control. The liquid cell was designed in three separate parts: a fixed reflector, a double walled hollow cylindrical arrangement for the liquid sample, and a heavy base to hold the cell with a transducer connection for excitation–detection. The diameter of the reflector was chosen as 16 mm. Generally, in commercially available systems, the reflector diameter is smaller or equal to that of a piezoelectric disk. In the present case, a 10 mm piezoelectric disk was used and the diameter of the reflector was kept greater than 1.5 times that of the disk to reflect optimum ultrasound. In the far field, the ultrasonic beam is

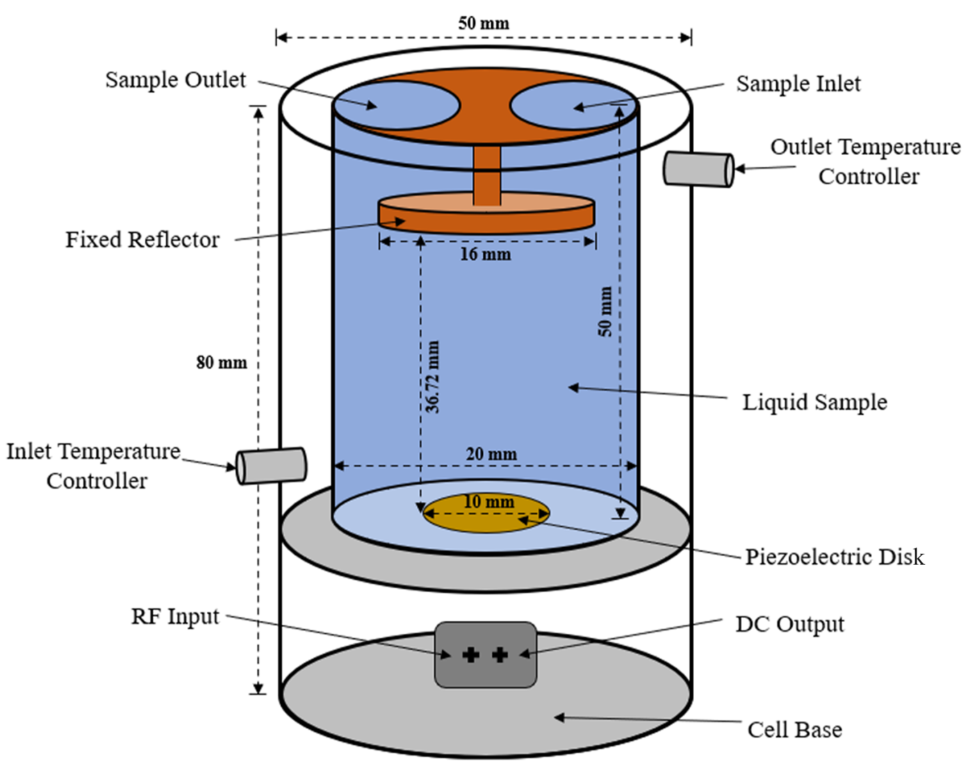

FIG. 4. Drawing of the developed sample holder with a fixed reflector and a constant separation distance between the transducer and reflector.

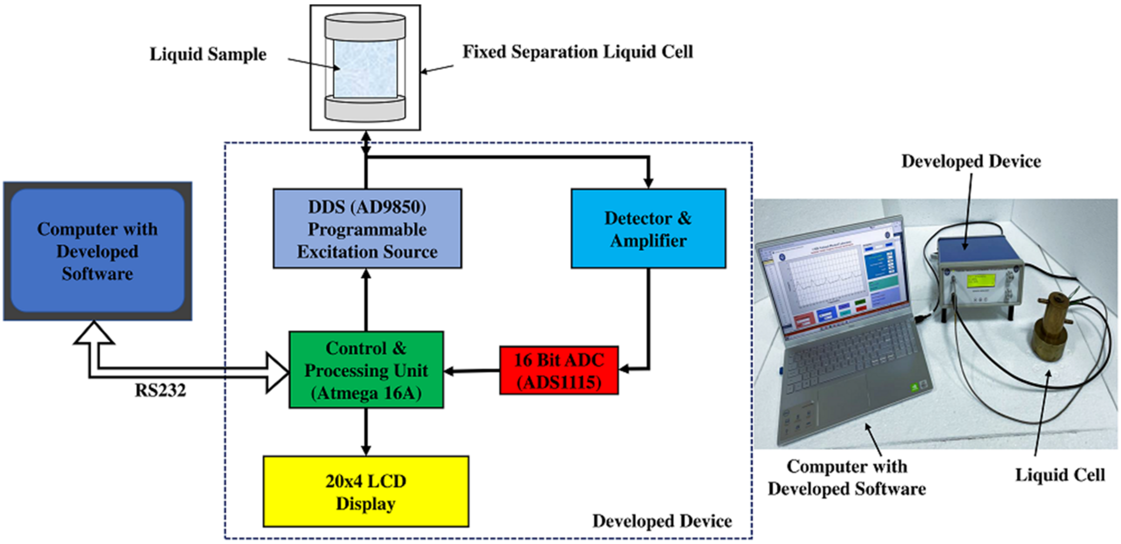

FIG. 5. Block diagram and image of the developed PC based sweep frequency ultrasonic interferometer.

diverged, and in the near field, the ultrasound is non-uniform. In the case of a smaller reflector, the amount of reflected beam depends on the reflector diameter. Therefore, these parameters were considered and optimized during cell development.

For velocity measurement in a fixed path ultrasonic cell, the distance between the disk and reflector plays a critical role. The frequency shift is decided by the separation of the reflector and transducer within a 3 dB bandwidth. A smaller distance between

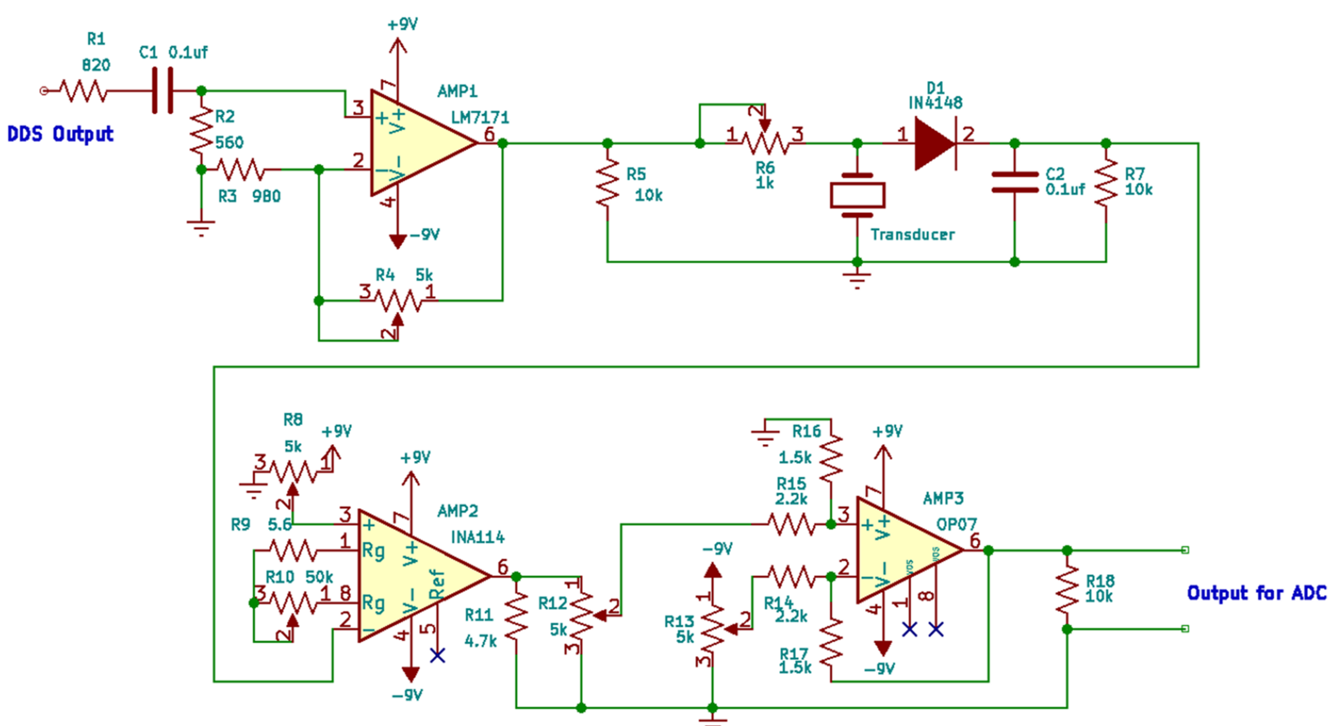

FIG. 6. Detailed signal conditioning circuit uses a single piezoelectric ultrasonic transducer as the transmitter and receiver.

the disk and reflector results in a larger frequency shift, and a larger distance increases the liquid volume of the cell. Therefore, the cell design was optimized to hold a liquid sample volume of less than 15 ml.

B. PC-based sweep frequency excitation and detection system

The concept of generating a precise frequency and fine sweep is based on a direct digital synthesis (DDS, AD9850) based RF generator.[17] The microcontroller, Atmega16A, was interfaced to the DDS module in parallel mode.[18] The program code was developed to generate fine frequency increments and decrements up to 1 Hz. The microcontroller is operating at a 16 MHz clock. Figure 5 shows the block diagram of the developed sweep frequency ultrasonic interferometer system.

The DDS module is operated at 125 MHz and has the capability to provide a step size of 0.1 Hz. The microcontroller program for frequency generation was written in Code Vision AVR. The widely preferred operating frequency of the ultrasonic interferometer is 2.0 MHz. Therefore, the default frequency has been selected as 2.0 MHz with a maximum frequency limit of 20 MHz. The frequency of the DDS module is updated by sending customized commands through RS232 to the microcontroller. The detailed signal conditioning circuit to utilize the same transducer as an ultrasonic transmitter and receiver is shown in Fig. 6. The signal generated at the output of DDS is about 1 Vpp at 2.0 MHz and further decreases with an increase in frequency up to 20 MHz. The upper frequency generation was limited to 20 MHz, as all the liquid characterization can be performed within this range. For this purpose, the amplification of the signal was performed with a wideband operation amplifier (IC LM7171) to boost the signal to the desired level.[19] The piezoelectric transducer was excited with a 5 Vpp amplitude. The ultrasound is generated using a piezoelectric transducer in the liquid sample, and upon the interference of the transmitted and reflected signals at the transducer, the standing waves are formed. Due to this, there is a small change in the electrical impedance of the transducer. The variation in signal is directly measured at the transducer end without a cable, with the help of a diode detection circuit. The detection circuit, having a parallel RC circuit, filters out the radio frequency signal and provides a constant DC output at a selected excitation frequency. Now, this DC amplitude depends on the electrical impedance of the transducer, which, in turn, depends on the superposition condition of the waves. Hence, maxima and minima can be measured from the detector DC. As the variation is extremely small, of the order of few millivolts, and is over the larger DC amplitude, a difference amplifier (IC, INA 114) is used with one terminal kept at an adjustable DC value. Furthermore, the operational amplifier OP07 is used to convert amplified ±9 V signal span into the 0–5 V level suitable for the 16-bit serial ADC (ADS1115 module),[20] which is managed using the microcontroller, and the data are sent to the computer upon request command.

C. Control, acquisition, and analysis software development

Personal computer-based control, acquisition, and analysis software was developed in Visual Basic. Figure 7 shows a snapshot

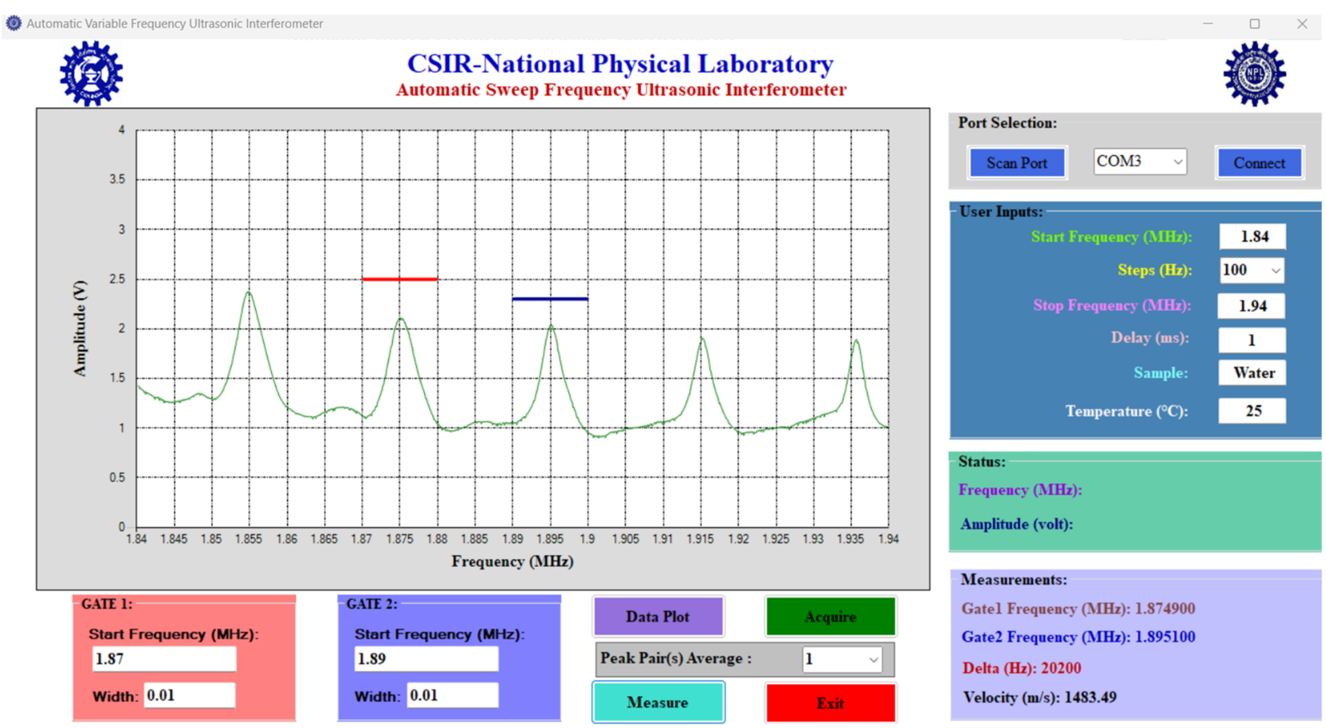

FIG. 7. Graphical User Interface (GUI) of the developed ultrasonic interferometer software.

of the graphical user interface (GUI) of the developed software. It has the capability to display corresponding voltages as a function of frequency and saves data in the form of a text file with all user selected parameters for future records. The measured frequency shift is used for the estimation of ultrasonic propagation velocity in liquids. The software also has the facility to automatically detect the peak amplitudes of selected maxima. Two consecutive maxima are used for the estimation of frequency shift (Δf). The software automatically calculates the ultrasonic propagation velocity. If required, multiple maxima can be acquired and averaging is used for a better precision.

The data acquisition for each sample is carried out with RS232 serial communication at an interval of 1 ms. The typical serial data read/write operation is performed at a higher baud rate of 115 200 for effectively faster data transfer to the computer. A sufficient delay of about 10 ms is assigned for ultrasound system stabilization and data acquisition at each frequency. With a 100 kHz frequency, sweeping in the full range results in 100 000 data points at 1 Hz step. It was observed that the total time required to perform one complete sweep over 100 kHz bandwidth was 10, 100, and 1000 s for 100, 10, and 1 Hz, respectively.

1. Ultrasonic velocity measurement

Ultrasonic velocity measurement with the developed system is performed by acquiring the amplified detected signal as a function of excitation frequency on a computer. Figure 8 shows the typical acquired signal by sweeping the excitation frequency from 1.84 to 1.94 MHz with a step resolution of 100 Hz.

For the best response and optimum signal variations, the transducer is preferred to operate close to its resonant frequency. There is a sudden shift observed in amplitude at the antinode due to the superposition of waves. The frequencies f_{n-2}, f_{n-1}, f_n, ... are the frequencies at the respective maxima. Two consecutive maxima frequencies are used to calculate the frequency shift (Δf), and ultrasonic velocity is estimated using Eq. (8).

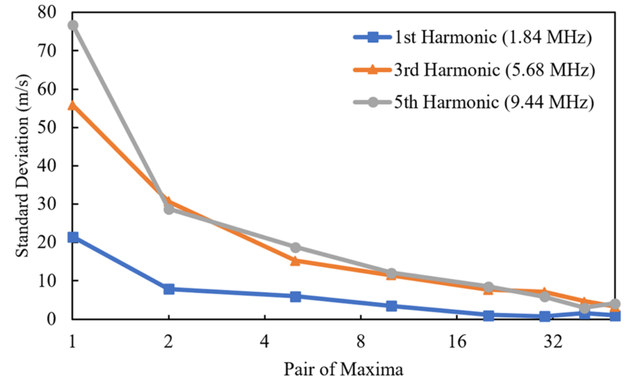

FIG. 9. Standard deviation in the measurement of ultrasonic velocity using the variable separation type interferometer in double distilled water.

D. Calibration of parameters

Various parameters affect the measurement of ultrasonic propagation velocity. Some of the important factors are considered and elaborated below.

1. DDS frequency accuracy (f)

The accuracy of the frequency generated plays a vital role in the overall accuracy of ultrasonic propagation velocity measurement. The literature on crystal oscillators reveals that an accuracy of the order of ±50 ppm can easily be achieved. The module can provide the best resolution of 0.029 Hz.[17] The excitation frequency calibration was carried out with the help of standards available and traceable to the National Primary Facility. The 32-bit tuning word is used for the generation of frequency, which can be limited as per requirements.

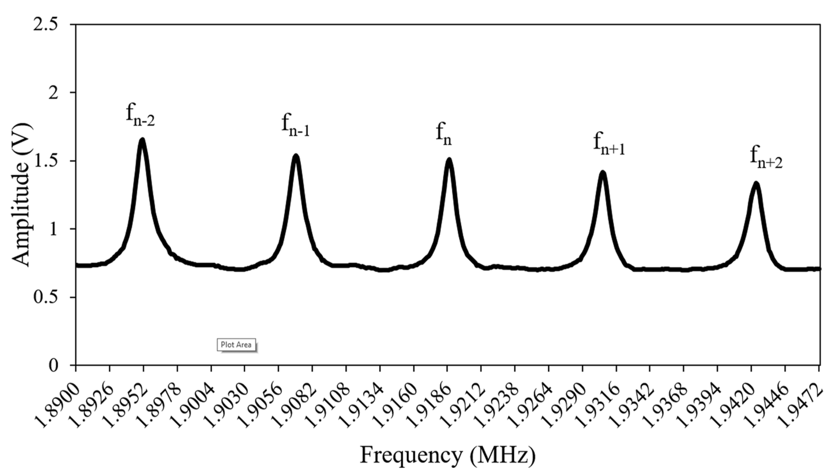

FIG. 8. Typical detected signal response received in the distilled water using the developed system at 100 Hz frequency step.

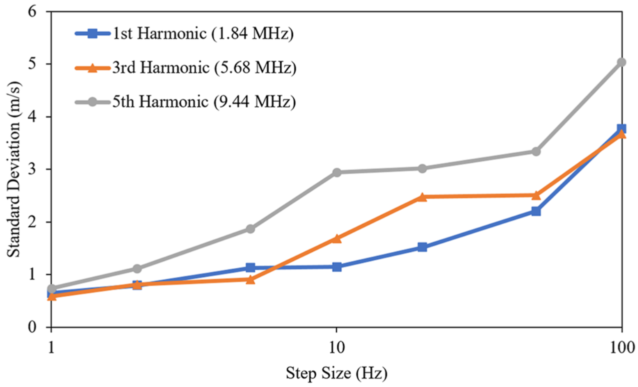

FIG. 10. Standard deviation in the measurement of ultrasonic velocity using the developed sweep frequency interferometer in double distilled water.

2. Separation between transducer and reflector (d)

In Eq. (8), it is clear that the separation between the transducer and reflector affects the measurement accuracy of ultrasonic progation velocity. Therefore, it needs to be calibrated. The developed fixed path cell was calibrated with the help of ultrasonic flaw detector (UFD) (Olympus: EPOCH 1000) using the pulse echo method at 25 °C. The measurement was repeated ten times. The average distance between the fixed reflector and transducer was 36.72 mm with a standard deviation of ±0.007 mm with 0.01 mm type B uncertainty of UFD. The overall uncertainty in separation between the transducer and reflector was 0.05%. Double distilled water was used as an experimental liquid for the calibration of the separation, and the temperature was maintained with an accuracy of ±0.1 °C.

IV. RESULT AND DISCUSSION

In variable separation ultrasonic interferometers, a better precision in velocity measurement is achieved by considering a higher number of maxima. However, the number of maxima is limited to the displacement (micrometer) range of the reflector and the ultrasonic wavelength in the sample under study. In general, commercial systems use a 25 mm displacement range. Furthermore, liquids with a higher ultrasonic velocity generate longer wavelengths, thereby limiting the total maxima in the range below 50. Therefore, the study of precision in ultrasonic velocity measurement was carried out by considering pairs of maxima from 1 to 50.

Figure 9 shows the standard deviation values in the measurement with different numbers of maxima pair consideration. It is clearly evident from the figure that a single pair of maxima considered in the measurement results in the highest standard deviation of 75 m/s at 9.44 MHz. Such a high standard deviation of about 5% in velocity measurement cannot be ignored. The impact can be seen to be significantly improved by considering many maxima pairs, which ultimately improves the deviation to 4.2 m/s at 50 maxima pairs. Measurement and counting for 50 maxima is extremely difficult, time-consuming, and prone to error. It is also obvious that the standard deviation depends on the ultrasonic frequency. Therefore, the method of variable separation seems more suitable and limited to lower frequencies.

Figure 10 shows the standard deviation values in the measurement by the developed sweep frequency approach at various frequency steps. It can be seen in Fig. 10 that the ultrasonic velocity measurement at 1 Hz step has the lowest standard deviation compared to higher step sizes. So, the step size plays an important role in determining the standard deviation in velocity measurements. With a decrease in step size or resolution, the standard deviation in velocity improved, but it significantly increased the measurement time to complete the desired sweep within the selected sweep bandwidth. At higher frequencies, the standard deviation in the measurement of ultrasonic velocity using a conventional variable separation interferometer goes high. It is clear that the developed technique shows a better measurement precision than conventional variable separation.

Furthermore, the functionality of the developed system has also been verified for liquids having lower velocities (carbon tetrachloride) and extremely higher velocities (glycerol).[21] The ultrasonic velocity of various liquids was measured at different temperatures. During the measurement, the ultrasonic laboratory temperature was observed and stabilized within ±0.1 °C.

Table I shows the measured velocity at different temperatures with a 10 Hz step size in various liquids, along with the literature values. The ultrasonic propagation velocity values measured are in good agreement with the literature values.

In the measurement of ultrasonic velocity by the sweep frequency approach, there are certain sources of error that need to be considered. From Eq. (8), it is evident that the error associated with the transducer and reflector separation (d) directly hampers the velocity measurement accuracy. Source frequency tolerance also becomes one of the contributing factors. The impact of these errors can be estimated directly and is mentioned in Table II, along with their degree of contribution.

TABLE I. Ultrasonic velocity measurement using the developed system in carbon tetrachloride, distilled water, ethylene glycol, and glycerol at different temperatures.

Sample \ Temperature	Ultrasonic velocity: Measured (literature)[22] (m/s)				
	10 °C	20 °C	25 °C	30 °C	40 °C
Carbon tetrachloride	961.62 (967)	932.6 (937)	918.33 (922)	910.75 (907)	866.66 (877)
Distilled water	1446.46 (1447.28)	1483.19 (1482.36)	1498.62 (1496.72)	1512.71 (1509.14)	1527.27 (1528.88)
Ethylene glycol	1689.85 (1691.5)	1664.99 (1670.5)	1659.74 (1660.0)	1644.87 (1649.5)	1630.18 (1628.5)
Glycerol	⋯	1908.78 (1929.5)	1902.2 (1920.0)	1887.26 (1910.5)	1872.79 (1891.5)

TABLE II. Various sources of error and their degree of contribution to the ultrasonic velocity.

Error source	Uncertainty	Error in ultrasonic velocity (literature)
Transducer–reflector separation	$\pm 17\ \mu$m	0.75 m/s (0.05%)
Frequency	± 50 ppm	0.005%
Temperature accuracy	$\pm 0.1\ ^\circ$C	0.25 m/s (0.017%)
Diffraction effect	⋯	0.075 m/s (0.005%)[23]
Attenuation change during frequency sweep (9.44–9.54 MHz)	0.044 m^{-1}	0.015 m/s (0.001%)[23,24]
Total type B error	⋯	0.794 m/s (0.053%)
Random error (type A)	⋯	0.651 m/s (0.043%)
Total uncertainty	⋯	1.027 m/s (0.068%)

The wavefront produced using the ultrasonic disk used in this experimentation is considered to produce a plane wave within a near field. However, the literature[23] in this field indicates little impact of diffraction in the measurement of ultrasonic velocity in the near field, which is of the order of 0.005%. However, for higher frequencies, which ultimately result in a larger value of the near field, the impact of diffraction may be completely ignored.

Since the ultrasonic attenuation [indicated in Eq. (2)] during the measurement at lower frequencies (1.84–1.94 MHz) is extremely low and the impact on velocity measurement is negligible, it can therefore be ignored. However, in cases of measurement at higher frequencies (9.44–9.54 MHz), the impact becomes noticeable. It was computed that the change in ultrasonic attenuation during the higher frequency sweep at 20 °C was 0.044 m^{-1}, which, in turn, affects ultrasonic velocity by 0.015 m/s.

V. CONCLUSIONS

A PC-based sweep frequency ultrasonic interferometer using single transducer and single DDS based excitation has successfully been developed. With the developed control, acquisition, and analysis software, maxima peak can be detected more precisely. Therefore, ultrasonic velocity measurement in terms of precision has been improved and is free from mechanical movement limitations. The functionality of the developed system has been validated for liquid velocities covering the lowest to highest (CCl_4 to glycerol). It is also evident that in the developed sweep frequency ultrasonic interferometer, the propagation velocity is directly proportional to the frequency change. The amount of frequency change (Δf) remains fixed and is independent of the transducer operating frequency, provided that the liquid is non-dispersive, hence allowing better measurement at higher frequencies.

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AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflicts to disclose.

Author Contributions

Nitin Dhiman: Conceptualization (equal); Data curation (lead); Formal analysis (equal); Funding acquisition (equal); Investigation (equal); Software (lead); Validation (equal); Visualization (equal); Writing – original draft (equal). **Sahil Sharma**: Conceptualization (supporting); Data curation (supporting); Formal analysis (supporting); Investigation (equal); Resources (equal); Writing – original draft (supporting). **Piyush**: Data curation (supporting); Formal analysis (supporting); Software (supporting). **Bishan Kumar**: Data curation (supporting); Validation (supporting); Writing – review & editing (supporting). **Sanjay Yadav**: Funding acquisition (supporting); Resources (supporting); Supervision (equal); Writing – review & editing (supporting). **P. K. Dubey**: Conceptualization (equal); Formal analysis (equal); Funding acquisition (equal); Project administration (lead); Resources (lead); Software (equal); Supervision (lead); Writing – review & editing (lead).

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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