Development and Application of 500MSPS Digitizer for High Resolution Ultrasonic Measurements

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Abstract

High resolution and high accuracy ultrasonic measurements demand the use of state-of-the-art data acquisition systems. Such measurements, which necessitate the use of high frequency ADCs, are frequently required in many industries. A 500MSPS digitizer board has been developed at Electronics Division, BARC to carry out precision ultrasonic measurements. The digitizer is an ISA bus compatible board and is based on Equivalent Time Sampling technique. In this approach, low frequency clocks are employed to achieve much higher effective sampling rates. This reduces the noise, power consumption and the cost. Since very high effective sampling rates are achieved with this board, high frequency transducers (up to 50MHz) can be easily employed.

A windows based GUI facilitates parameter setting, information & waveform display and cursor based measurements. A special software routine, that utilizes correlation technique followed by cubic spline interpolation, has been developed to accurately measure the time-of-flight between two successive back wall echoes. The base sampling rate of 500MSPS along with the use of correlation approach results in achieving the accuracy of the order of 1 nanosecond or better in the time-of-flight measurement. When translated in terms of distance in metals, this corresponds to accuracy of the order of few microns.

This board, along with a pulser/receiver serves as a setup suitable for carrying out ultrasonic measurements in very thin objects (like tubes, plates etc.) either in contact or in immersion mode. The acquisition delay (from excitation pulse in contact mode or from surface echo in immersion mode) can be varied from 565ns to 1840ns in steps of 5 nanoseconds. The data acquisition window available for measurements (after acquisition delay) is 3500 nanoseconds. This is equivalent to an approximate thickness of 7.5 mm in stainless steel.

The board has been applied for wall thickness mapping in thin tubes at Quality Assurance Division of BARC. The measurements made on the tube were also verified by sectioning the tube and finding out the true thickness using high resolution profile projector. The measurements have been observed to match excellently with the true measured values.

This paper describes the technical features of the digitizer board and discusses some of the results of its evaluation.

Keywords: Equivalent Time Sampling, acquisition delay, effective sampling rate, acquisition window, correlation, cubic spline, time of flight
1. Introduction
High resolution and high accuracy ultrasonic measurements necessitate usage of high frequency transducers. Ultrasonic inspection systems using high frequency transducers also require high speed ADCs for accurate sampling, storage and subsequent reconstruction of the echo signals received from such probes. In the conventional approach, direct digitization of the signals of interest is carried out at very high frequencies using high speed ADCs. However, due to presence of high frequency circuits and signals, the overall noise level as well as the power consumption tends to be higher. The system cost also tends to be higher due to the higher cost of high speed devices. The card developed by the authors is based on the principle of Equivalent Time Sampling\(^1\) technique and operates with much lower clock frequencies. Hence the noise level is much lower. The highest clock frequency used on board is 1MHz. The board offers a simple and cost effective solution for high resolution thickness/thickness-variation/velocity measurements in thin metallic samples.

2. Principle of Operation and brief Description of the Digitizer Board
Figure 1 illustrates the principle of operation of the digitizer board. The top portion shows the waveform of the amplified echo signal received from the pulser/receiver. The echo signal of interest (marked within the acquisition window) is digitized sequentially by acquiring one sample during each excitation, with successive shifting of the sampling window (in time) in subsequent excitations. This shifting is achieved by comparing a linear ramp signal with a variable reference voltage as shown in the figure. Thus, with the help of this digitizer board, one acquires a portion of A-scan, corresponding to the acquisition window. Facility has been provided to position this acquisition window along the A-scan vector by providing selectable acquisition delay. The board can be used in both, contact and immersion modes. In contact mode, the acquisition delay starts immediately after the excitation pulse (as shown in the figure) while in the case of immersion mode, it starts with the onset of first echo (i.e. surface echo) after the excitation pulse. The digitized data is stored in an on board First-In-First-Out (FIFO) type of memory. After acquisition of the entire data corresponding to one position of the probe, the stored data is transferred to host PC for storage, information display and analysis.

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Fig. 1: Equivalent Time Sampling technique used by the digitizer board

- **T\(_{AD}\)** - acquisition delay
- **T\(_{ACQ}\)** - acquisition window
- **T\(_S\)** - sampling time
- \(F_S = 1/T_S\)
Electronic circuits on the board comprise of fast peak detector, precision ramp generator, delay generator, 12 bit quad DAC, fast S/H, ADC, FIFO, sequence controller, PRF generator and PC interface logic. Most of the digital control logic has been implemented in a Field Programmable Gate Array (FPGA). A watchdog timer indicates the non-availability of the echo signal which may occur either due to insufficient amplitude of surface echo (in immersion mode) or a probable disconnection of the probe or cable (in contact mode). The amplified echo input is buffered and provided as an additional output for viewing the complete A-scan waveform on an external oscilloscope. Figure 2 shows the photograph of the digitizer board.

A LabWindows based graphical user interface has been developed for controlling various parameters on the board and display, process and analyze the acquired data.

3. Salient Technical Specifications of the Digitizer Board

Following are salient hardware and software features of the digitizer board:

3.1 Hardware Features:
   a) Effective digitization rate : 500 MSPS Max. (User selectable from 500/250/125/62.5/31.25/15.625 MSPS)
   b) Analog bandwidth : 100 MHz (min.)
   c) Resolution : 8 bits
   d) Acquisition window : 3500 ns approx.
   e) Acquisition delay : 565 ns to 1840 ns (User selectable in steps of 5 ns)
   f) Scanning type : Contact/Immersion
   g) PRF output : 1, 2, 5, 10, 20 or 50 kHz (TTL compatible)
   h) Board size : 18cm x 11.7 cm ISA bus based PC add-on type

3.2 Software Features:
   a) Graphical User Interface (GUI) for setting user selectable parameters e.g. sampling rate, PRF, acquisition delay, number of averages, mode, material etc.
b) A-scan display in the form of a graph (Amplitude vs. Time)
c) Up to 256 averages of the acquired data, to improve signal to noise ratio
d) Thickness and thickness-variation measurements & display
e) Amplitude spectrum display for a select portion of A-scan data and automatic calculation of peak frequency etc.

3.3 Software routine to measure Accurate Time of Flight
A software routine has been developed to measure the time of flight accurately. This routine implements correlation technique followed by cubic spline\cite{2} interpolation to accurately measure the time-of-flight between two successive back wall echoes. User needs to place three cursors across the two back-wall echoes between which the time-of-flight is required to be measured. The accuracy achieved in time-of-flight measurement using this approach (along with the 500MSPS sampling rate of the digitizer board) is estimated to be of the order of 1 nanosecond or better. When translated in terms of distance in metals, this corresponds to accuracy of the order of few microns.

4. Calibration of the Digitizer Board for Ultrasonic Measurements
The ultrasonic measurement accuracy that can be achieved with the digitizer board is checked using a standard step-wedge block (Krautkramer make) with known sound velocity of 5.944 mm/microsecond. The thickness of the block is first measured with 1 micron resolution micrometer and the reading is 2.551mm. The thickness (2.552 mm) measured with the help of our digitizer board is observed to be very close to the true thickness of the block as measured with the micrometer. Several measurements were made to ensure the repeatability of the test system. The measured value was always found to be very close to the true value. Figure 3 shows the screen print of the GUI in the process of these measurements. The lower waveform (in A-scan window) shows the part of the A-scan captured along with three overlay cursors which cover two back wall echoes selected for measurement. The upper waveform (in correlation window) shows the result of correlation of these two echoes. After applying cubic spline interpolation at these two peaks the accurate time-of-flight and consequently thickness is measured. The measured thickness (2.552mm) can be seen inside the A-scan window.
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5. Application of the Digitizer Board for Ultrasonic Measurements
The digitizer board has been used for wall thickness mapping in thin Zircaloy tubes (wall thickness = 0.45mm) at Quality Assurance Division, BARC. Figure 4 shows the block schematic of the setup used for the application. The setup consists of the 500MSPS digitizer installed in an industrial PC, pulser/receiver unit (JSR model: DPR300[3]), 20MHz point focus immersion transducer probe and a water tank holding the tube. The digitizer board generates the PRF trigger that is routed to the pulser/receiver unit which generates sharp voltage spike that excites the 20MHz probe. The receiver section of the pulser/receiver amplifies the reflected echo signals. The amplified echo is routed to the digitizer for sampling and storage. The measurement accuracy of the board was established by taking four readings, 90degree apart, at a particular cross section of the tube and then verifying those by cutting and viewing the section under high resolution profile projector. The comparison between the actual thickness as measured by the profile projector and the ones determined by the digitizer board are given in Table 1 below. The excellent match, between the thickness measured with the help of our digitizer board and that obtained using the profile projector, indicates the very good measurement accuracy achieved in wall thickness mapping of the tubes.
Fig. 4: Immersion setup used for wall thickness mapping of 0.45mm Zircalloy tubes

Table 1: Comparison between actual and measured thickness in a thin zircalloy tube.

<table>
<thead>
<tr>
<th>Location</th>
<th>Actual thickness as measured with the profile projector (mm)</th>
<th>Thickness measured with the Digitizer board (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.494</td>
<td>0.492</td>
</tr>
<tr>
<td>B</td>
<td>0.474</td>
<td>0.467</td>
</tr>
<tr>
<td>C</td>
<td>0.459</td>
<td>0.453</td>
</tr>
<tr>
<td>D</td>
<td>0.485</td>
<td>0.482</td>
</tr>
</tbody>
</table>

Figure 5 shows screen print of one of the measurements during thickness mapping of the 0.45mm Zircalloy tubes.
Fig. 5: Screen print of GUI showing A-scan, selection of two echoes for time-of-flight measurement, their correlation plot and measured thickness of 0.455mm in Zircalloy tube.

6. Conclusion:
Consequent to a detailed evaluation, the 500MSPS Digitizer board developed at Electronics Division, BARC has shown its ability to carry out high resolution and accurate thickness measurements based on ultrasonic technique. As it provides accurate measurement of time-of-flight (1ns or better), it is very useful for precise and accurate dimension measurements of industrial components such as thin tubes and plates. It can also be employed to carry out accurate velocity measurements for newer materials.

7. References
[1] Explanation of Equivalent Time Sampling technique can be found at following sites:
