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Hardware Developments of an Ultrasonic Tomography Measurement System

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Abstract: This research provides new technique in ultrasonic tomography by using ultrasonic transceivers instead of using separate transmitter-receiver pair. The numbers of sensors or transducers used to acquire data plays an important role to generate high resolution tomography images. The configuration of these sensors is a crucial factor in the efficiency of data acquisition. Instead of using common separated transmitter – receiver, an alternative approach has been taken to use dual functionality ultrasonic transceiver. A prototype design of sensor's jig that will hold 16 transceivers of 14.1mm has been design. Transmission-mode approach with fan beam technique has been used for sensing the flow of gas, liquid and solid. This paper also explains the circuitry designs for the Ultrasonic Tomography System. *Copyright © 2011 IFSA.*

Keywords: Transceivers, Ultrasonic tomography system, Non-invasive imaging.

1. Introduction

Process tomography refers to a method of acquiring the internal characteristics of pipelines flows or process vessel reaction from the measurements on the domain of interest. Current industries are

increasingly interested in this field as tomography brings much applications as well as advantages to the system. Over two decades of research worldwide, process tomography has become a routine research tool in many research laboratories and is being accepted for process measurement and control in some industrial applications. In chemical process, tomography will be useful to estimate the spatial distribution of phases and chemicals inside their processing vessels or pipelines, giving instant feedback on reaction processes, or efficiency of transport. The 3D images can be reconstructed from non-invasive peripheral sensing which make it easier to monitor the internal reaction of online process. In pharmaceuticals and fine chemicals, monitoring the critical processes of high value products is essential, and in the food industry, tomography offers great insights into the structural transformations found in colloids and gels. In mineral engineering, tomography can monitor separation and transport operations continuously, helping ensure maximum production. While in the oil and gas industries, process tomography can deliver valuable information for a variety of processes such as, characterization of multiphase flows, separation of multiphase components and homogeneity of packed beds and process vessels [1, 14]. In addition, process tomography can be valuable tool in testing and validation of process models such as computational fluid dynamics (CFD).

2. Ultrasonic Process Tomography

Various techniques exist in process tomography, so the best and suitable technique should be choose depends on the components inside the vessels in this case solid, liquid and gas. Ultrasonic process tomography is useful for imaging processes where differences in object density and elasticity offer the most significant sensing opportunity [2]. In general the object will interact with an ultrasound beam through some form of acoustic scattering. The interaction may then be sensed to yield information about the object or field [3].

There are three types of sensing techniques which is transmission mode, reflection sensing mode and diffraction mode [4]. In this paper, the transmission-mode technique was utilized. The transmission mode technique is based on the measurement of the changed in the properties of the transmitted acoustic wave. Then, it gives advantages over the other techniques since there are three different intensity of material in the measuring pipe which gives different acoustic impedance of each material. The systems consists of ultrasonic pulse generators to excite the transducers to transmits and receive the waves. The information gathered then will be process to develop the reconstructed images of components inside the process vessels.

In the study of tomography, the physical principle of a sensing systems depends on the reconstructed image of the cross sectional distribution of the parameter. It is evaluated by arraying ultrasonic sensors non-invasively on the surface of the vessel. By using the electronic circuits to interface, the data captured can be processes and analyzed by the computer to reveal the information of the internal dynamic characteristics [5, 7].

3. Hardware Developments

One of the most important parts in ultrasonic tomography system is the front end that is the transducer array and associated electronic hardware. This is important for acquiring the data needed to produce a meaningful image. This is fundamental to the success or failure of an acoustic imaging system. Therefore, given the object to be imaged and the specifications to be achieved, the design of the front end of an acoustic imaging system should be regarded as a first priority [8].

3.1. Hardware Developments

Ultrasonic transceiver is a type of transducer that converts electrical energy into high frequency sound waves and also converting sound waves back to electrical energy. It contains piezoelectric crystal materials that have the ability to transform mechanical energy into electrical energy and vice versa [7]. Piezoelectric crystals have the property of changing size when a voltage is applied, thus applying an alternating current (AC) across them causes them to oscillate at very high frequencies, thus producing very high frequency sound waves.

For using piezoelectric transceiver, certain characteristics need to be evaluated to determine the properties of the transceiver that suitable for specific application. For instance, the size, frequency, sensitivity, beam angle, driving voltage and others. Selection for the right transceivers is the first priority since it is in the front-end of the ultrasonic tomography system together with associated hardware. Other factors that contribute to the selection of the sensor are the sound pressure level (SPL) and the centre frequency shift against temperature variations [9].

3.2. Sensor Arrangement

A sensor jig as in Fig. 1 was designed to put the sensor into order well around the pipe vessel. It was fabricated to fit 16 transceiver of size 14.1 mm. The jig is created with accurate position, angle and thickness for each sensor. The use of sensor jig will reduce the error of the projected signal due to the echo effect [10].

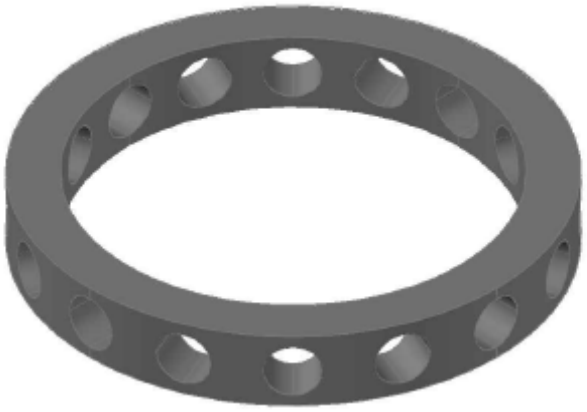

Fig. 1. Sensor Jig.

All 16 transceivers are enclosed in the jig that designed for 100 mm pipe diameter. This situation shows the advantage of using transceiver rather than using separate transmitter receiver sensor. Since the number of sensors may improve the quality of reconstructed image, transceivers are the best choice. Transceivers have dual functionality which can be switch either as transmitter or receiver. Thus, it will give about half extra space to locate the transceiver around the pipe. For example, by using common ultrasonic sensors functioning separately, only 8 transmitters and 8 receivers can be applied instead of using dual functionality transceiver, 16 sensors be able to installed.

When a transceiver is set to be transmitter, the other transceiver will be functioning as receivers. It will be connect to transmitter circuit when function to transmit and connect to receiver circuit when function to receive. The timing circuit is very important since incorrect switching timing leads to inaccurate measurement data [11].

The cross section of the sensor arrangement shown in Fig. 2 which is also an example of fan shaped beam sensor array. The transceivers enable the transmission and reception on the same sensor.

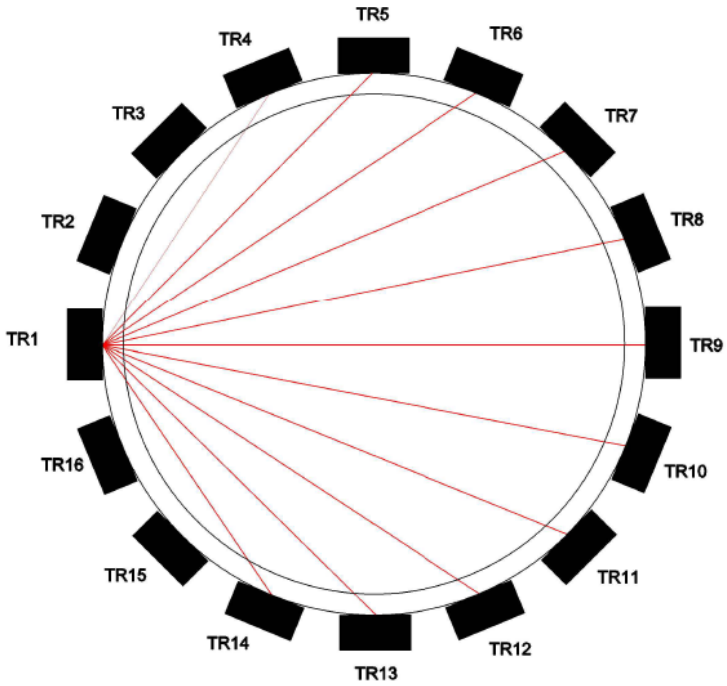

Fig. 2. Ultrasonic Transceivers Sensor Arrangement.

The transceiver chosen has 125° beam angle and from Fig. 2, it clearly shown that only 11 transceiver are within the region. The other 5 are outside the boundary including the excite one. So, there are 11 measurement in one projection, therefore totally 176 measurement will be obtain. Compared to separate transmitter receiver with same beam angle on a same diameter of pipe and same sensor size only, 6 sensors within the boundary with total of 48 measurements will be taken. Therefore results in image generated that much fuzzier.

3.3. Electronic Circuit

In tomography system, the front-end is important as it need to obtain data with high accuracy since the measurement data are used for image reconstruction part. The Fig. 3 shows the block diagram of ultrasonic tomography system. The microcontroller unit (PIC18F4520) is used as signal generator to generate a 40 kHz signals to transmitters while the receiver will received the projected signals [8, 12]. The readings from receiving transceivers are sent to the signal conditioning circuit. The output of this circuit will go through peak detector circuits which then are sent to personal computer via USB connection from the DAQ system for image reconstruction. In this research, the Data Acquisition System, NI USB 6218 from National Instruments is use to acquire and transfer the data via LabView software.

The signal generator circuit was designed using low noise high-performance; internally compensated operational amplifiers built using Texas Instruments complementary bipolar Excalibur process, which act as comparator as shown in Fig. 4. The comparator will generate 30 Vp-p tone burst of 40 kHz with reverberation delay of 100 Hz. The duration for every pulse generation is chosen because within this delay time, the reverberation effects will stop before new excitation is activated.

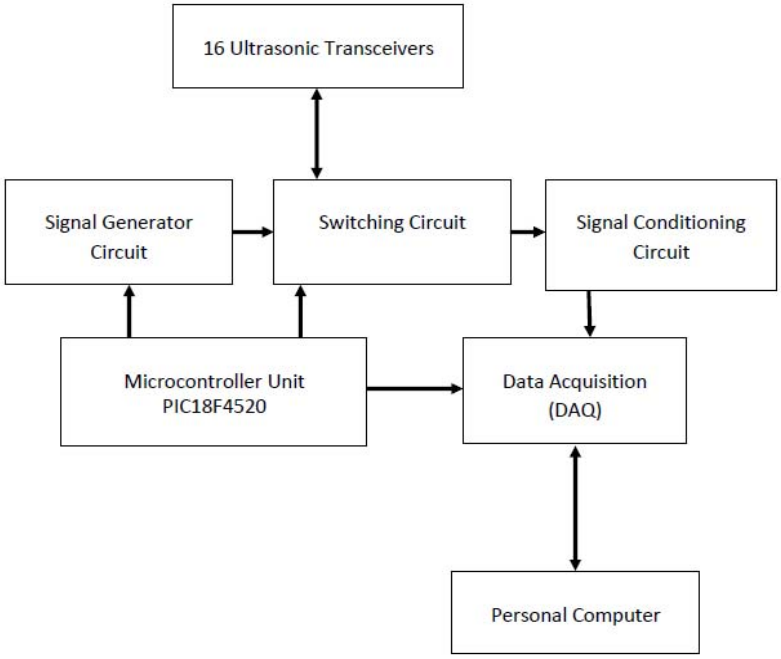

Fig. 3. Block Diagram of Ultrasonic Tomography System.

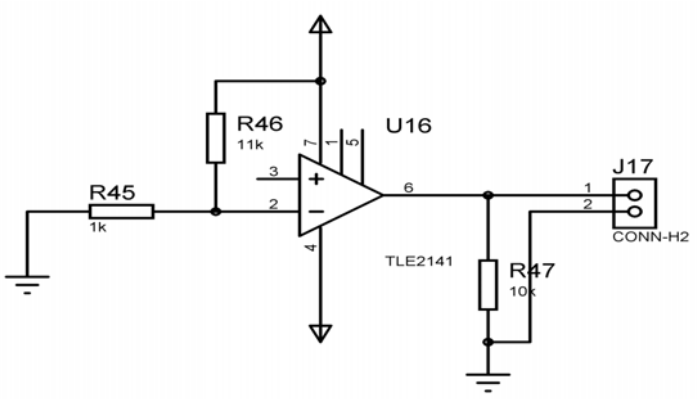

Fig. 4. Signal Generator Circuit.

The signal conditioning circuit consists of two components which is signal receiving circuit and peak detector circuit as shown in Fig. 5 and Fig. 6. The receiving circuit which also is an amplifier circuit using the audio operational amplifier, LM833. This op-amp is a high speed op-amp with excellent phase margin and stability. The amplifier was design in two stages with inverting amplifier connection. The first stage is the pre-amplifier with gain AA = -120 and the second stage is to amplify with gain AB = -120. The received signals are amplified through these two stages to amplify twice.

A peak detector is a series connection of a diode and a capacitor outputting a DC voltage equal to the peak value of the applied AC signal. The circuit is shown in Fig. 6, an AC voltage source applied to the peak detector, charges the capacitor to the peak of the input. The diode conducts positive half cycles charging the capacitor to the waveform peak. When the input waveform falls below the DC peak stored on the capacitor, the diode is reverse biased, blocking current flow from capacitor back to the source.

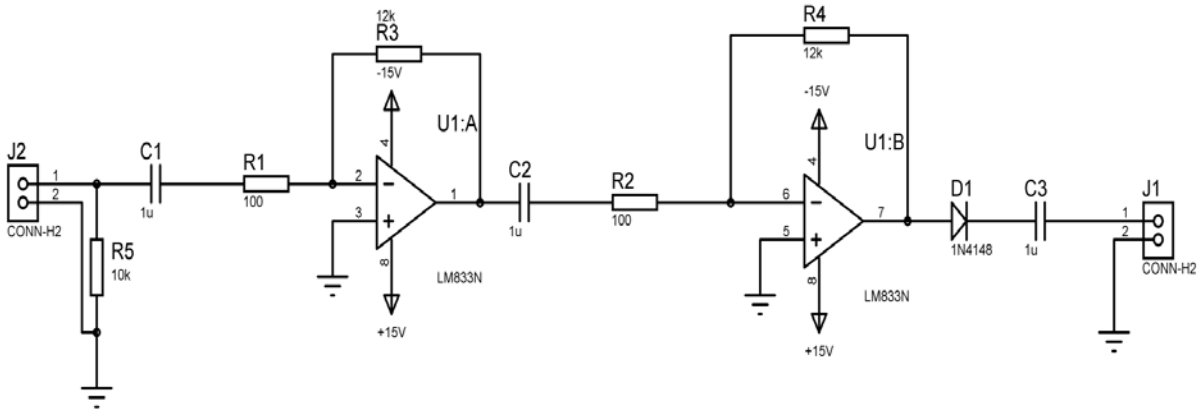

Fig. 5. Signal Receiving Circuit.

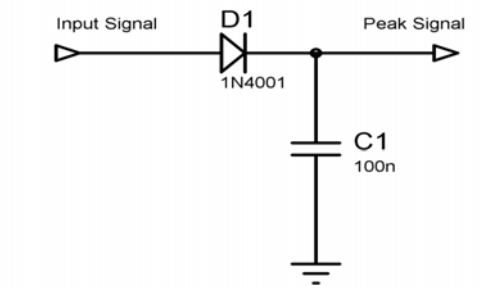

Fig. 6. Peak Detector Circuit.

4. Results

The signals shown in Fig. 7 are transmitting pulse tone of transmitter 1 (yellow) and receiving signal by the receiver 9 (blue) captured using oscilloscope. Amplifying the received ultrasonic signals is vital because the original receive signal might be too small and hard to process in the next level. However, the amplified gain must not be too large as the output signal will saturated in which the signals might be clipped out at positive and negative peak. This will bring an error to the final results. As be seen in the receive wave, there is a slight distortion occur. This is because, the wave are going through several layer before reaching the receiver. It has to penetrate the pipe wall then go through the water or components inside and break in the wall again before reaching the receiver.

Peak detector output is shown in Fig. 8 (blue). It changes AC ultrasonic wave from the receiver signals above into a DC voltage. The peak detector will capture the most high peak signal to be changed to DC signal. Then, the highest voltage as shown in Fig. 8 will be taken for further imaging reconstruction. The implementation of this peak detector circuit will give faster response time as well as simpler integration into the system and also for more compact board design [13].

5. Conclusions

The use of transceiver proved to give more spaces and furthermore extra data can be collected which gives better results in image reconstruction later on. The use of peak detection concept in the circuitry systems gives much simpler and less complexity in signal conditioning circuits. It will automatically detect the peak signal of the ultrasound wave. Nevertheless, the system has to bear out of heavy noise so that the peak detector would not sample the false data. Thus the system needs to be robust.

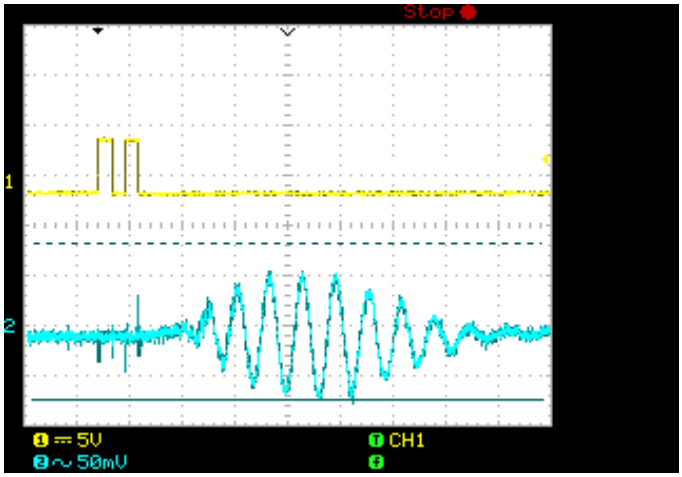

Fig. 7. Ultrasonic Pulse tones and Receiver Signals.

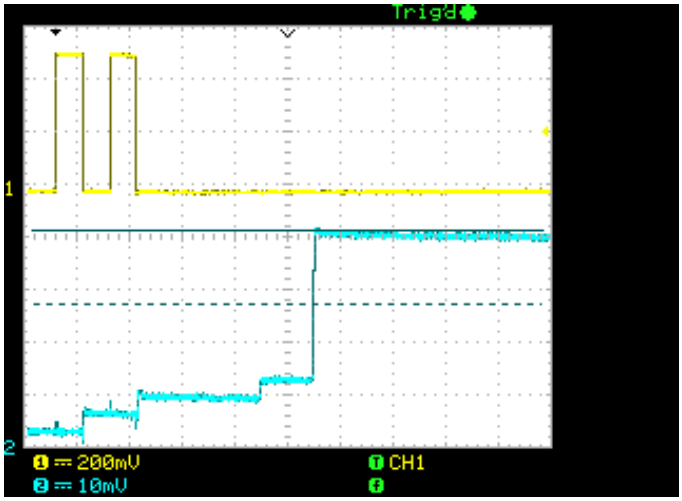

Fig. 8. Peak Detector Output.

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on Sensor Device Technologies and Applications

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August 21-27, 2011 - French Riviera, France

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Submission deadline	March 23, 2011
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- Sensors signal conditioning and interfacing circuits
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Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

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