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Ultrasound Processing Circuitry for Ultrasonic Tomography

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Abstract- **The development of an ultrasonic transmission tomography system is described. The system is intended for the imaging of two component flows (such as gas/water) inside pipes of industrial processes. Transmission-mode approach has been used for sensing the gas/liquid two-phase flow, which is a kind of strongly inhomogeneous medium. A prototype fixture of vertical column and a prototype design of sensor's jig for ultrasonic tomography imaging are used. The fixture of the vertical column is designed to hold the sensor's jig that will have the 16-pairs of ultrasonic sensors attached to it. The investigations were based on the transmission and the reception of ultrasonic sensors that were mounted circularly on the surface of experimental vessel. This paper also explains the hardware and circuitry design for the Ultrasonic Tomography System. Detailed explanation are presented on the sampling circuits used to sample the ultrasonic wave which is then to be sent to the personal computer (PC) for end-user interpretation which will display the reconstructed tomography images.**

Keywords- **Ultrasonic tomography, Liquid and gas flow, Sample and hold, Peak detection, Image reconstruction.**

I. INTRODUCTION

PROCESS monitoring plays an important role in most areas such as in industries and research field. Widespread need for the monitoring of the internal activities of process plants arises to further improve the design and operation of the process plant. Thus, process tomography has the requirements of providing the solutions on the need of such monitoring system with the advantage of providing quantitative data of the internal behavior without disrupting the process plant [1].

The oxygen transfer rate in aerobic fermentation is an important parameter in the design and operation of bioreactors. Aerobic organisms need oxygen for growth, product formation, and cell maintenance. Thus, adequate transfer of oxygen must be maintained. Transfer of oxygen from a gas phase to a liquid phase is complicated by presence of cells, product formation, ionic species, and antifoaming agents. These can alter bubble size and liquid film resistance, which affect oxygen solubility.

Ultrasonic Tomography has the advantage of providing a monitoring system able to reconstruct the distribution of a gas/liquid two-phase flow over the cross-section of a pipe while being non-invasive and possibly non-intrusive to the corresponding activities inside the column [2].

This paper represents the configuration of tomography system by using ultrasonic sensors to visualize the internal behavior of the column without harming the process plant system or destroying the process plant in order to monitor the internal activities. Process tomography that is being implemented in this project will then be able to monitor the internal process non-invasively [1].

II. HARDWARE CONFIGURATION

A tomography system design usually consists of 3 main parts: (a) sensory unit, (b) signal conditioning circuit and data acquisition system and (c) image reconstruction software [3]. The sensory unit implemented in this project consists of a numbers of ultrasonic transducers with a resonant frequency of 333 kHz. The sensors placement has been designed to interrogate the sensing area from many different viewing angles as shown below in Fig 1. When transmitting ultrasonic wave it is important to match the impedance of the transducer to that of the vertical column (acrylic) to maximize the energy transmitted [4], [5].

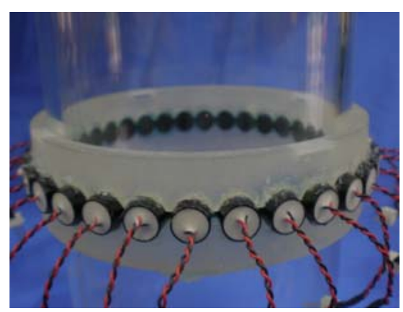

Fig. 1. Sensory unit consists of 32 ultrasonic transducers.

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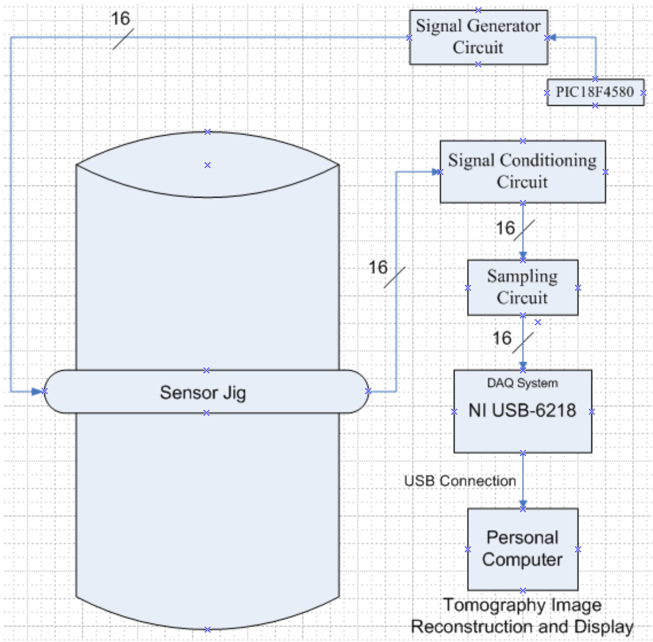

Fig. 2. Block Diagram of Ultrasonic Tomography system

The signal conditioning circuit is used to acquire and amplify the raw measurements from the ultrasonic sensors. The output of the sampling circuit is then used by the computer to display the resulted images from the image reconstruction software.

III. Sampling Circuit

When a receiving transducer receives the transmitted ultrasonic wave signal, the output value is in continuous time. This paper discusses the two different methods used for the Sampling Circuit in Fig. 2, to acquire data from the ultrasonic sensors before the measurements are sent to the personal computer.

A. Peak Detection

The peak detection method utilizes the use of a peak detector circuit (Fig. 3) that determines the peak voltage on an AC ultrasonic wave and converts it into a DC voltage as shown in the image in Fig. 4.

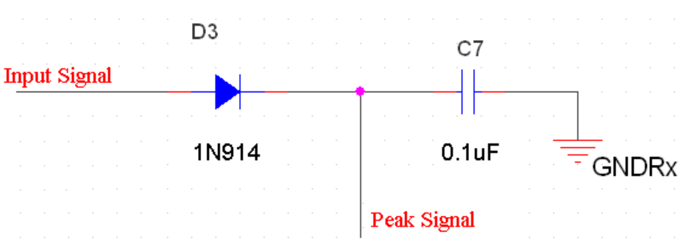

Fig. 3. Peak Detector circuit

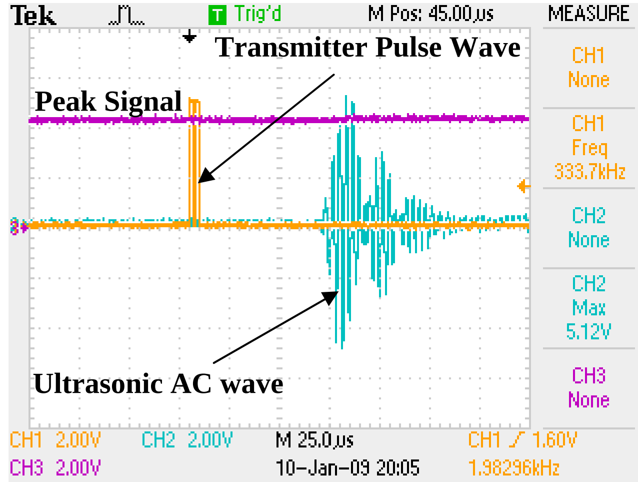

Fig. 4. Peak Detection Sampling

Peak Detector circuit constructed for this method is used to measure the strength of the transmitted signal received from the ultrasonic transmitter to the receivers. Its implementation is also because of its faster response time, simpler integration into the system and also for more compact board design.

B. Sample and Hold

A sample and hold circuit is used to interface real-world signals, by changing analogue signals to a subsequent system such as an analog-to-digital converter. The purpose of this circuit is to hold the analogue value steady for a short time [6]. A capacitor is used to store the analogue voltage and digital switching is used to alternately connect and disconnect the capacitor from the analogue input. The rate at which this switch is operated is the sampling rate of the system.

The Sample and Hold Circuit using the LF398N IC from National Semiconductor are used to input the AC signal from the ultrasonic receiver signal and output the DC voltage value of the sampled ultrasonic input (Fig. 5). The DC values are then used to determine the strength of the transmitted ultrasound signal.

Choosing the capacitors for use in a Sample and Hold circuit as the hold capacitor is very important. The most important characteristic to observe for when choosing capacitors for use in this application is their Dielectric Absorption (DA) ability. The hold capacitor used is from Polypropylene type as they have low DA.

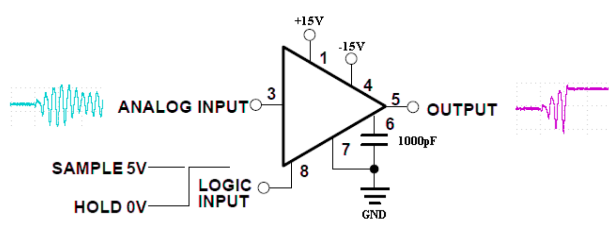

Fig. 5. Typical Sample and Hold circuit

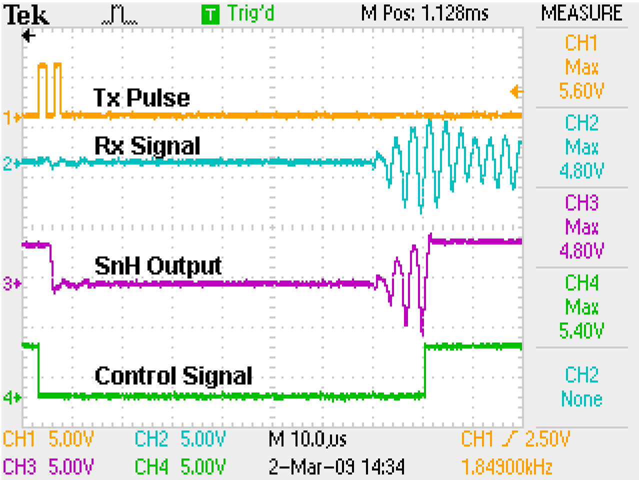

Fig. 6. Sample and Hold Signal

Fig. 6 above shows 4 signals that explains the working concept of a Sample and Hold circuit. The top signal labeled as Tx Pulse is sent from the microcontroller to an ultrasonic sensor to excite the transmitting transducer. A receiving transducer will pick up the signal and convert the pulse signal into ultrasonic AC wave signal (Rx Signal). The Control Signal from a microcontroller is used to trigger the LF398N IC when to sample or hold the Rx Signal.

IV. RESULTS

A development of an Ultrasonic Tomography Prototype (Fig. 8) was constructed which is based on the Peak Detection technique. 32 ultrasonic transducers are used in this prototype which is configured using 16-pair of transmitters and receivers, Peak Detector circuit are used to sample the ultrasonic wave signals at the end of each receiver.

To analyze the reconstructed images from the Ultrasonic Tomography Prototype, "Computed Tomography Simulation Software" developed by Mohd Hafiz Fazalul Rahiman is used. The Computed Tomography (CT) software (Fig. 7) is able to choose from many different phantoms for tomography image reconstruction for education or research purposes.

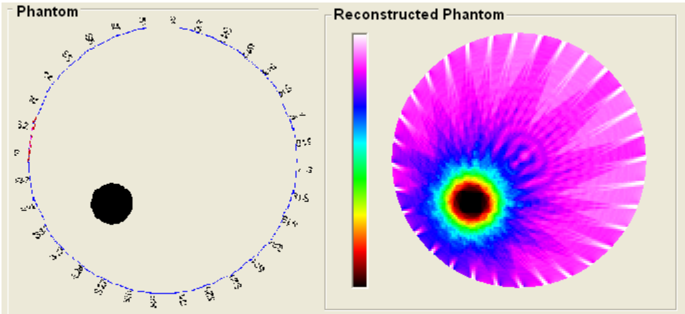

Fig. 7. Phantom Reconstruction tomogram

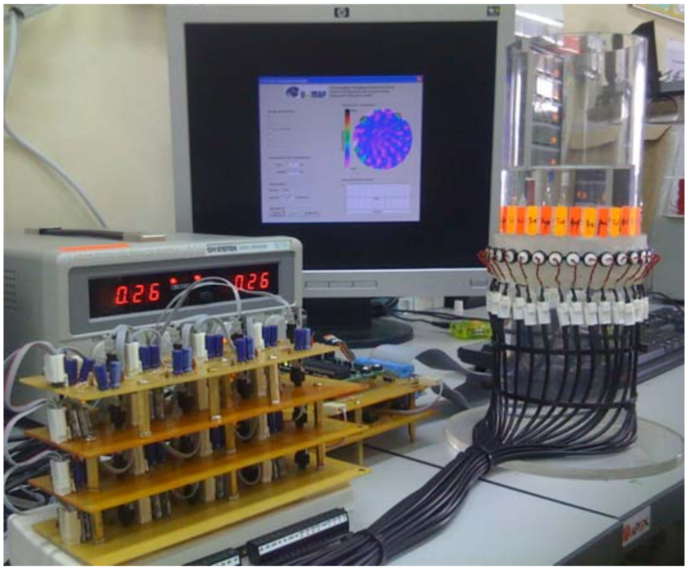

Fig. 8. Ultrasonic Tomography Prototype

To review the performance of both sampling circuits, an experimental model were built as illustrated in Fig. 9. The experiment model consists of the experimental pipe (vertical column) which is filled with liquid (water). A test model is used to simulate the presence of gas in the column.

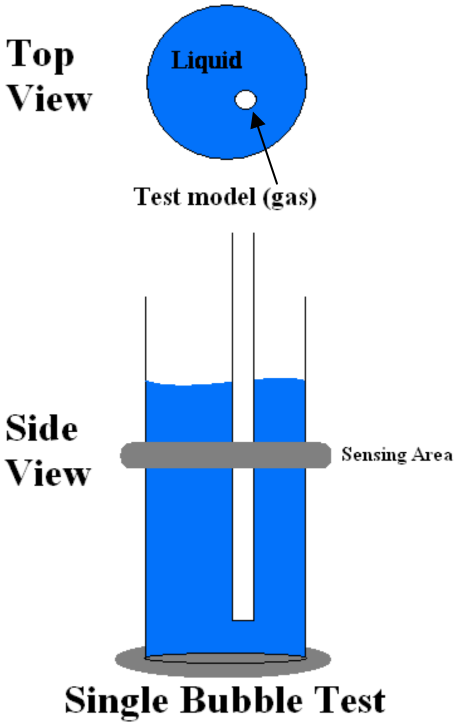

Fig. 9. Experiment Model

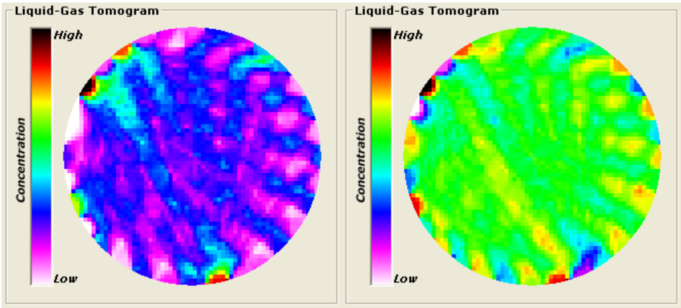

Fig. 10. Liquid-Gas Tomogram

As shown in Fig. 10, the left image is when there is no test model (gas) inserted into the vertical column while the right image shows the condition when a test tube is inserted in a position shown in Fig. 9. The resulted image shows clear difference for gas detection. However the important parameters such as gas size, shape and location are not attainable.

V. Discussion

Further analysis is done to investigate the real cause for the missing parameters attained from the Ultrasonic Tomography Prototype tomograms as illustrated below in Fig. 11.

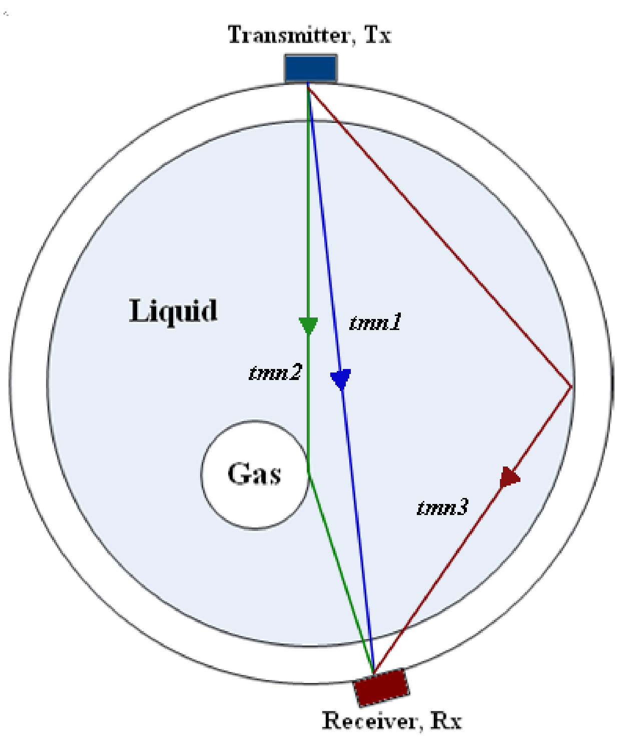

Fig. 11. Three possible paths for receiving signals

There are 3 possible paths for the receiving signals from the transmitter to a receiver [7]. The receiving signals may come from the direct transmission (*tmn1*), the reflected signals by gas component surfaces (*tmn2*) and the reflected signals against the pipe wall (*tmn3*) as shown in Fig. 12.

The problem that arises by using the concept of peak detection instead of the sample and hold circuit is that in some cases, the reflected signals of *tmn2* are stronger than the direct transmission of *tmn1* (Fig. 13).

This scenario happens when the gas bubble are near to the path of the direct transmission, thus much of the transmission signal will hit the gas component surfaces and will then received by the receiver. The peak detector circuit will then register the peak value of *tmn2* instead of the desired signal of *tmn1*. This results in false data collection.

Shown below is the image of the actual ultrasound signal received from a receiver. The main signal that is of the importance for the Ultrasonic Tomography Prototype's sensing electronics is the signal that comes from *tmn1* which is from the direct transmission between a transmitter and a receiver. Transmission-mode approach requires monitoring this particular path to determine the presence of gas medium in liquid/gas two phase flow.

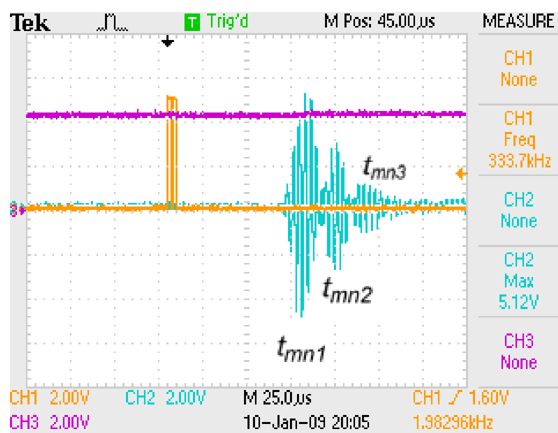

Fig. 12. Ultrasound signal received by a receiver

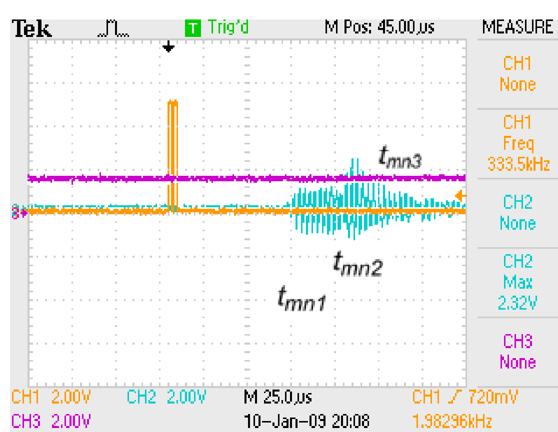

Fig. 13. False data collection when using peak detector

VI. CONCLUSION

The Peak Detection concept proves to be much simpler, less hardware integration and less complex for use in the Ultrasonic Tomography sensing electronics. The circuit also has the most advantage of operating as a stand-alone part by automatically detecting the peak signal of the ultrasound wave. However as the peak detection concept has been proved to have a chance for false data collection as shown in the discussion, it is not robust for use.

The working concept of a Sample and Hold circuit is to discriminate the exact information (information by the observation time). A sample and hold circuit is a circuit that captures and holds an analogue voltage in a specific point in time under control of an external circuit (in this case, microcontroller) [8]. This method guarantees better data collection than using peak detection concept. However this method is not available to work as a stand-alone part. Careful initialization needs to be done to determine which observation time is to be monitored. Implementing the sample and hold circuit into the signal conditioning circuit for each receiving sensors also demand more components to be used and more layout space which eventually results in bigger board design.

REFERENCES

[1] M.H. Fazalul Rahiman, Z. Zakaria, R. Abdul Rahim. Ultrasonic Process Tomography Imaging Sensor: An Analysis on Transceivers Sensing Method, 2008, 4th International Colloquium on Signal Processing and its Applications, Kuala Lumpur, Malaysia.

[2] Lijun Xu *et al.* Application of ultrasonic tomography to monitoring gas/liquid flow, 1997, Chemical Engineering Science, Vol. 52. No. 13, pp. 2171-2183.

[3] Ruzairi Abdul Rahim, Chan Kok Seong, Chan Kok San, Mohd Hafiz Fazalul Rahiman. Hardware development for Mobile Sensor in Electrical Capacitance Tomography. International Conference on Control, Instrumentation and Mechatronics Engineering, 2007, Johor Bahru, Johor, Malaysia.

[4] Johnson W.B. 2004. Design and Testing of a Laboratory Ultrasonic Data Acquisition System for Tomography. M.Sc, Virginia Polytechnic Institute and State University.

[5] M.H. Fazalul Rahiman, R. Abdul Rahim, Z. Zakaria. Design and modelling of ultrasonic tomography for two-component high-acoustic impedance mixture. Sensors and Actuators A 147, 2008, pp. 409-414.

[6] Béla G. Lipták, 2003. *Instrument Engineers' Handbook:* Process control and optimization. CRC Press.

[7] Mohd Hafiz Fazalul Rahiman, Ruzairi Abdul Rahim, Mohd Hezri Fazalul Rahiman, Mazidah Tajjuddin. Ultrasonic transmission-mode tomography imaging for liquid/gas two-phase flow, IEEE Sensors Journal 6 (6), 2006, pp.1706-1715.

[8] Fazalul Rahiman, M.H. 2008. Non-Invasice Imaging of Liquid/Gas Flow Using Ultrasonic Transmission-Mode Tomography. M.Eng Thesis, Universiti Teknologi Malaysia.