Feasibility Study on Water Temperature and Pressure Sensing based on Wireless Passive SAW Technology

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ABSTRACT

The conventional methods in monitoring water distribution system require batteries as power supply for sensor nodes. These methods are unreliable because the risk of damaging batteries is high especially in harsh environment. Wireless passive surface acoustic wave (SAW) sensors do not need direct power supply like batteries for the sensor nodes. In this research, a feasibility study on water temperature and pressure sensing by using wireless passive SAW technology was undertaken. A wireless passive SAW temperature and pressure delay line sensor was adapted in a designed framework which can simulate water temperature and pressure changes in the pipeline. The experimental results show that wireless passive SAW sensor worked properly in this designed framework. There is only slight attenuation on response signals in the framework compared to the open-air environment. The related phase delays of the response signals depend linearly on the temperature (pressure) when the pressure (temperature) keeps constant, which meet the theoretical analysis of the sensor node design.

Keywords: SAW sensor, water distribution network, pressure

1 INTRODUCTION

Real time monitoring is of great importance for water supply, pipeline protection as well as leakage detection in water distribution system. In current water distribution industries, active (direct power supply is needed) sensor systems are used for monitoring pipelines. The active sensor nodes are powered by rechargeable batteries. Energy harvesting units are developed for charging the batteries [1][2]. This method is unreliable because of the high risk of damaging batteries in harsh environment e.g. extreme weather conditions. Moreover, the design complexity of energy harvesting units is high which will lead to capital expenditure for a water distribution company to invest.

To improve system reliability, reduce maintenance cost, and alleviate power consumption in water distribution networks, wireless passive SAW sensor systems have strong potentials to be used to replace the classic active sensor systems. Wireless passive SAW sensor nodes can be accessed wirelessly. They are activated to work by receiving radio frequency (RF) pulses, so batteries are not required as direct power sources. They are ruggedized devices which can work in harsh environment reliably. They are small elements and can be manufactured by microelectronic technology, which leads to a low cost. The wireless passive SAW sensor systems can potentially decrease the maintenance cost by reducing the complexity of the entire monitoring system structure and increase system reliability [3].

The present work aims to study the feasibility on using wireless passive SAW temperature and pressure delay line sensor for sensing water temperature and pressure. The structure of the sensor node is introduced and analysed. Based on the previous work [4] for the initial experiment set up, the following experiment was undertaken. The sensor node was adapted in a designed framework which can simulate water temperature and pressure changes in the pipeline. The experiment results are analysed and discussed.

2 SENSOR NODE STRUCTURE

Figure 1 shows the sensor node of the wireless passive SAW delay line temperature and pressure sensor node with the antenna. In order to achieve better experiment performance, the performance of various antennas were investigated, the connected antenna was changed from the spiral type in the previous study [4] to this current type for enhance the signal strength. Figure 2 shows the structure of the wireless passive SAW temperature and pressure delay line sensor, which consists of a SAW delay line with an antenna connected with the Inter Digital Transducers (IDT). The sensor node is activated by RF pulses received through the antenna. In this case, the SAW sensor node contains a minimum number of elements and there are no direct power supply components, such as batteries, in this design. The outside pressure applied through the action point is different from the reference pressure inside the sensor. The pressure differences act on the left part of the substrate, and the temperature affects the whole substrate at the same time by the bonding basis on the right side of the substrate. The RF signals can be received and sent through the connected antenna and converted by the IDT. Reflectors are manufactured in parallel with the IDT on the substrate to reflect the SAW. Two are located at the right side of the IDT (R2 and R3) and one is on the left (R1). Such a design can fully use the two opposite directions SAW energy propagating from the IDT [5].

The dimensions of the top surface of the substrate change with the change of temperature and pressure. Consequently, the time delays caused by the SAW propagations are different, which leads to the phases shift. In the case of this SAW sensor, the interrogator transmits a pulse signal, and the sensor responds with a chain of pulses depending on the positions of the reflectors arranged on the substrate's surface. The different time delays between two or more response signals are evaluated. The current pressure and temperature information is acquired from the response signals through the subsequent signal processing.

Figure 1. The wireless passive SAW delay line temperature and pressure sensor node with antenna.

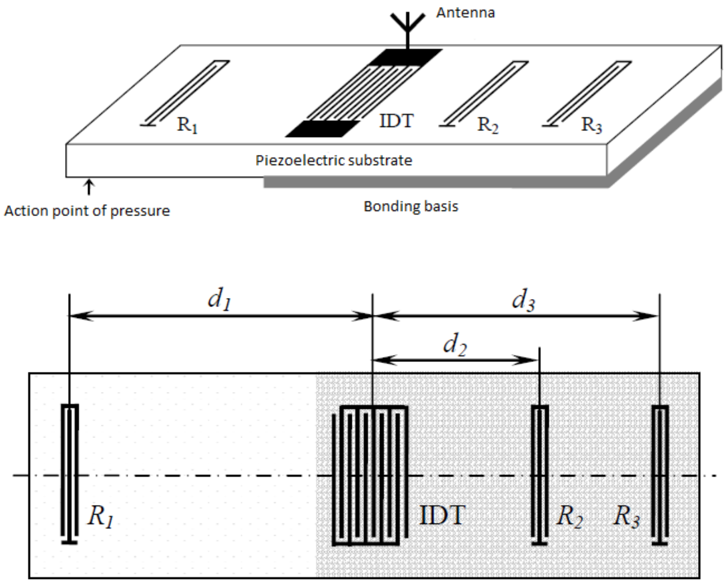

Figure 2. The structure of the wireless passive SAW delay line temperature and pressure sensor node.

3 EXPERIMENT DESIGN

Figure 3 is experiment design concept for evaluating passive SAW delay line temperature and pressure sensor node, the signal generator, the signal analyser and the oscilloscope work as the function of the reader for the wireless passive SAW sensor node. The practical experiment set up is shown in Figure 4. The temperature is controlled by the water bath, which is connected to the outer layer of the glass tube. Water with specific temperature circulates between the water bath container and the outer layer of the glass tube. The castor oil pressure control platform is connected to the strictly sealed inner chamber of the glass pipe. Based on the Boyle's Law, the pressure applied via the platform is equal to the air pressure sensed by the sensor node. The Function/Arbitrary Waveform Generator (Agilent 33220A) generates the pulse signal to mix with the standard 425

MHz sine wave generated by the ESG Vector Signal Generator (Agilent E4438C). The multiplication result of the two signals is transmitted out as the interrogation signal to the sensor node. The 1 GHz Mixed Signal Oscilloscope (Agilent MSO6104A) and the Spectrum Analyser (HP 8563E) receive and process both the interrogation signal and the response signals. Based on the previous research, the centre frequency of these sensor nodes is 425 MHz, and the best interrogation pulse width is 1 μs [4]. The following experiments are undertaken by the above settings.

The changes of actual temperature and pressure can be read from the temperature and pressure control platforms, while the experimental values can be obtained through the data of the interrogation and response signals received and processed by the signal analyser and the oscilloscope.

Based on the theory of SAW and the sensor structure, the relations between the phases and the temperature and pressure values can be described by the following equations,

$$T - T_0 = A(\varphi_T - \varphi_{T_0}) \quad (1)$$

$$P - P_0 = B(\varphi_{PT} - \varphi_{P_0T_0}) - C(T - T_0) \quad (2)$$

where T and T_0 are the temperature value and the initial temperature value respectively. φ_T is the temperature related response signal phase delay, and φ_{T_0} is the initial value of φ_T. A is a constant value related to the sensor structure and materials. Similarly, P and P_0 are the pressure value and the initial pressure value respectively. φ_{PT} is the both temperature and pressure related response signal phase delay, and $\varphi_{P_0T_0}$ is the initial value of φ_{PT}. B is a constant value related to the sensor structure and materials. C is a constant only related to materials.

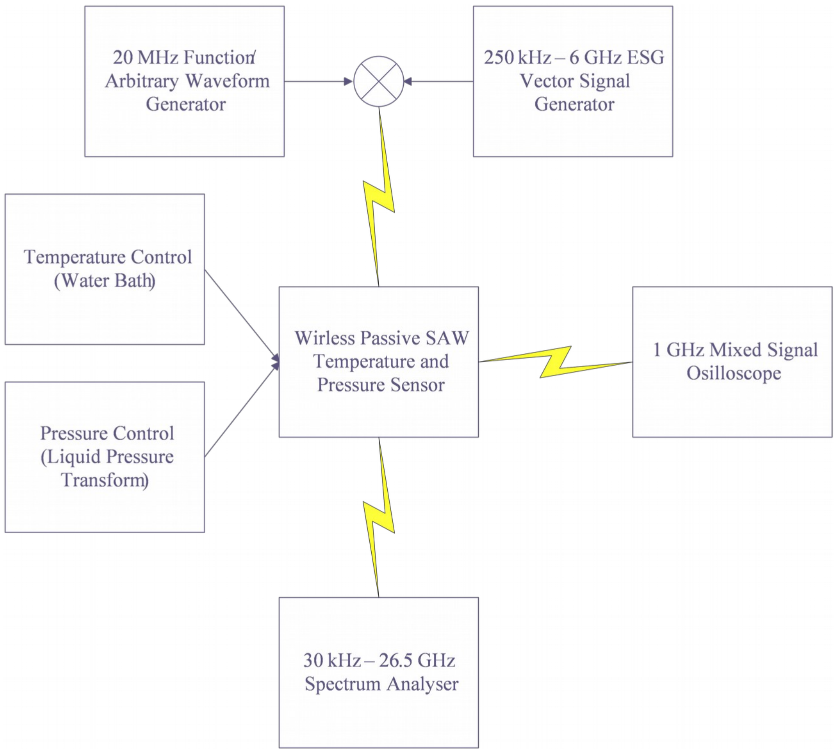

Figure 3. Experiment set up

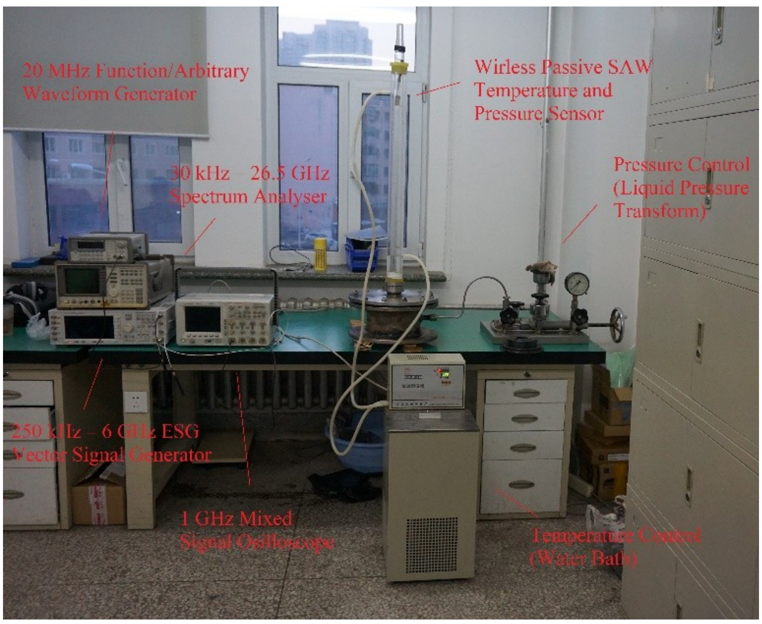

Figure 4. The practical experiment set up.

4 RESULTS AND DISCUSSION

Wired and wireless interrogation approaches for the sensor nodes were undertaken respectively. The results and analysis are compared and shown in Figure 5. The attenuation of the wireless response signals of passive SAW is high against the wired ones. Furthermore, the attenuation increases with the increase of the signal amplitude. There is an average 1/5 attenuation on the response signal when wireless interrogation and response signal receiving process is applied.

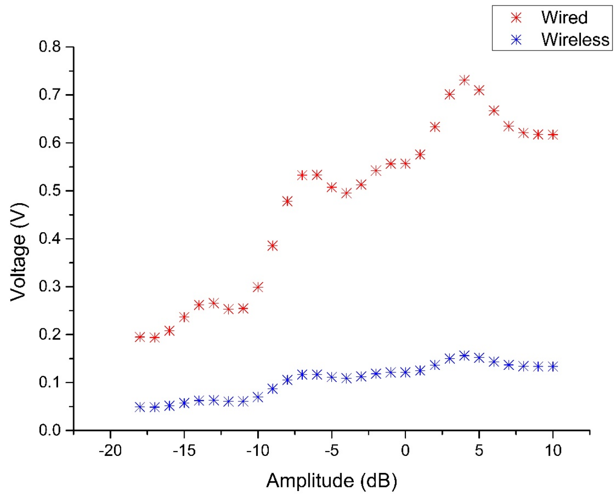

Figure 5. The attenuation of the received wireless signal against the wired signal.

The response signals reflected by R_2, R_3 and R_1 through air and water are compared and analysed. The results are shown in Figure 6-8 respectively. These figures indicate that generally the response signals when the passive SAW sensor node is in the experiment container, which is simulating the water pipeline environment just have slight attenuation against the ones when sensor node is in the air. Therefore, the attenuation caused by water could be ignored in the practical engineering environment.

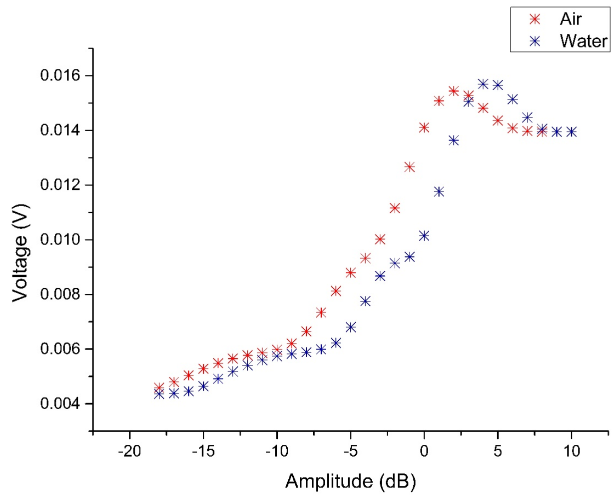

Figure 6. The comparison of the response signals reflected by R2 when the SAW sensor node was put in the air and in the simulating water pipeline condition.

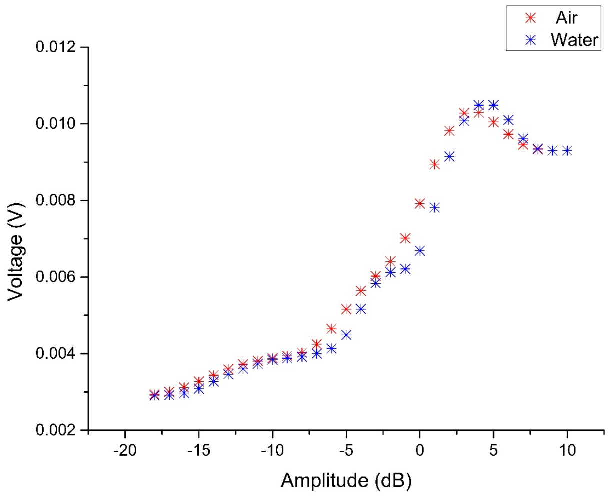

Figure 7. The comparison of the response signals reflected by R3 when the SAW sensor node was put in the air and in the simulating water pipeline condition.

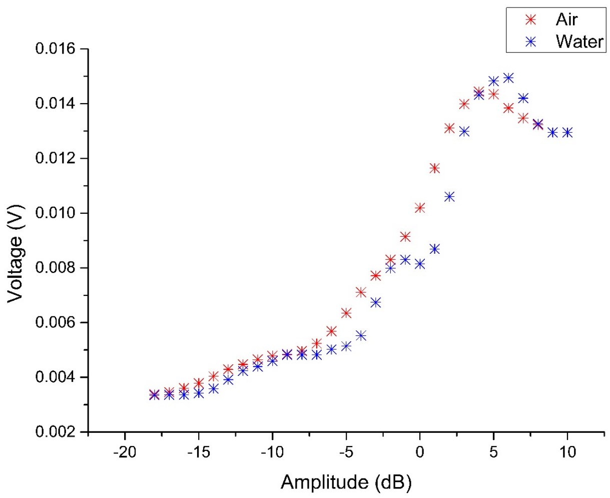

Figure 8. The comparison of the response signals reflected by R1 when the SAW sensor node was put in the air and in the simulating water pipeline condition.

Based on theoretical discussion for this type of wilress passive SAW delay line temperatue and pressure sensor in Equation (1) and (2), the related phase delays of the response signals depend linearly on the temperature (pressure) when the pressure (temperature) keeps constant. The experimental results are shown in Figure 9 and Figure 10. From these two figures, the experimental results meet the theoretical relations well, which demonstrates temperature and pressure values can be estimated by the phase delays.

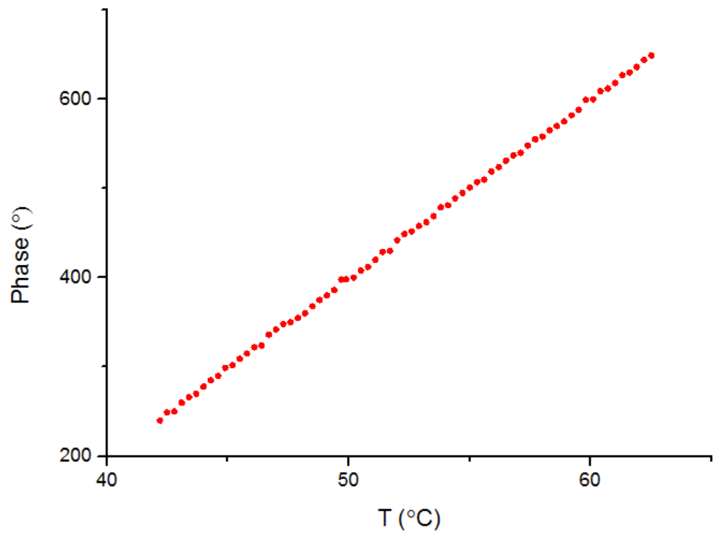

Figure 9. The relation between the phase delay and temperature when the pressure keeps constant.

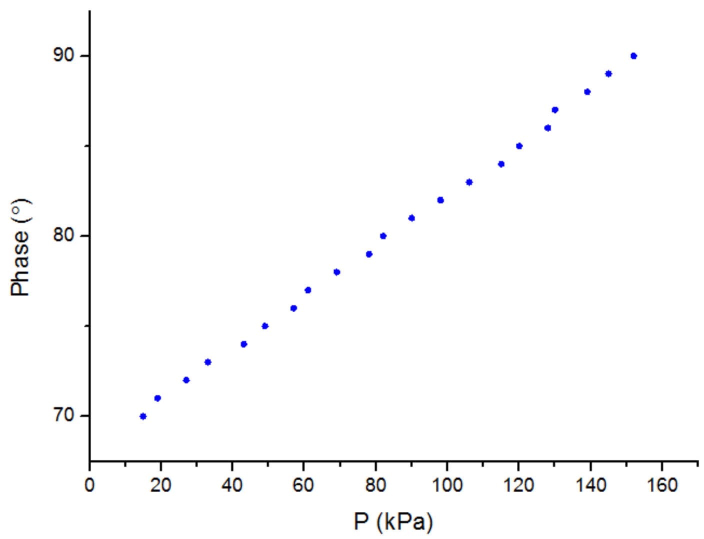

Figure 10. The relation between the phase delay and pressure when the temperature keeps constant.

5 CONCLUSIONS

A wireless passive SAW temperature and pressure delay line sensor was adapted in a designed experimental framework which can simulate the temperature and pressure changes in the water distribution pipelines. The magnitudes of the wired and wireless response signals are compared. There is a 1/5 attenuation on the response signal when wireless interrogation and response signal receiving process is applied. The response signals of the sensor node in different ambient environments are analysed and compared. Compared to the open-air environment, there is only slight attenuation of the response signals when the sensor node is planted in the designed experimental framework. The related phase delays of the response signals depend linearly on the temperature when the pressure keeps constant, and the related phase delays of the response signals depend linearly on the pressure when the temperature keeps constant. The experimental results meet the theoretical relations well.

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