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SAW Sensor Based on High-Resolution Delay Time for Temperature Measurement

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1. Background and Objective

Surface acoustic wave (SAW) devices were widely used as electronic components today. The basics of a SAW device are inter-digital transducer (IDT) and reflective gratings made of metal films on a piezoelectric material substrate [1]. Based on the piezoelectricity, IDT can convert electrical energy into mechanical energy to generate SAW or receive the electric energy converted from SAW reversely. Thus SAW devices were usually used for acoustic-electric element, such as filters, resonators, and oscillators. Other applications include sensors and identification tags.

A SAW tag is a passive device which will not be limited to the lifetime of a battery. Further, SAW tags combined with temperature sensor were proposed [2]. The phase change of the reflected signals was affected by temperature variation. Other studies discussed RFID SAW tag affected by temperature variation, and signal processing could adjust the temperature of the resolution to ± 0.2 °C [3,4]. The techniques of time position encoding and phase encoding for SAW tag were also proposed [5].

In this study, we used coupling of modes model (COM model) to analyze and design SAW tags. The digital signal processing was adopted to improve resolution of the delay time. By rising the resolution of SAW signal in time domain, the delay time variation in different temperature were analyzed and then the SAW tag can be applied to measure temperature precisely.

2. Design SAW Tag with COM model

COM model was corrected by Abbott can be used to simulate the conversion between surface acoustic wave and electric signal [6]. In this study, we used COM model to analyze SAW tag that was based on time position encoding proposed by Härmä et al. [5] **Fig.1** shows the encoding concept. One group means the delay distance which consists of 5 slots. One reflector was placed in every group. In a group, the 5th slot is a spacer to other groups, and it so did not be placed any reflector. Every slot provides 0.1 μs delay time for SAW, which represented different encoding (1-4). In addition, the "Start" and the "End" reflectors were the time delay reference.

Figure 2 show the result calculated by COM model. **Fig. 2(a)** was the return loss in frequency domain. The dip represented the excitation frequency about 433 MHz. The frequency sweep range was 100 MHz. **Fig. 2(b)** time domain reflected signal converted from return loss by inverse fast Fourier transform (IFFT). Ten reflective peaks in time domain consisted with our design.

In order to increase the resolution in time domain, we filled the same value in 380 MHz that down to 1 MHz and 480 MHz that up to 7501 MHz in frequency domain. Thus the frequency sweep range become 100 MHz to 7500 MHz, and the resolution increased from 0.01 μs to 0.13 ns in time domain. Then wave packages inside peaks of **Fig. 2(b)** was observed as the example shown in **Fig.3**.

3. Temperature Measurement with COM model

The delay time shift in different temperature. Temperature coefficient of delay (TCD) was usually used in the piezoelectric material. The formula was defined as follows:

$$TCD = \frac{1}{\tau}\frac{\partial \tau}{\partial T} = \frac{1}{l}\frac{\partial l}{\partial T} - \frac{1}{v_0}\frac{\partial v_0}{\partial T} \quad (1)$$

The above equation can be rewritten as

$$\tau' = \tau \cdot (1 + TCD \cdot \Delta T) \quad (2)$$

TCD was draw into COM model, and then we calculated the relationship between delay time and temperature. **Fig. 4(a)** shown the relationship between delay time and temperature of End

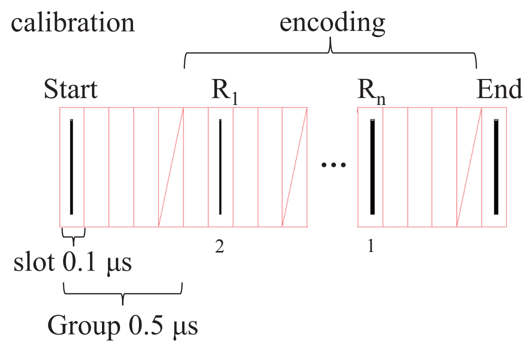

Fig.1 The schema of a SAW tag designed by time position encoding

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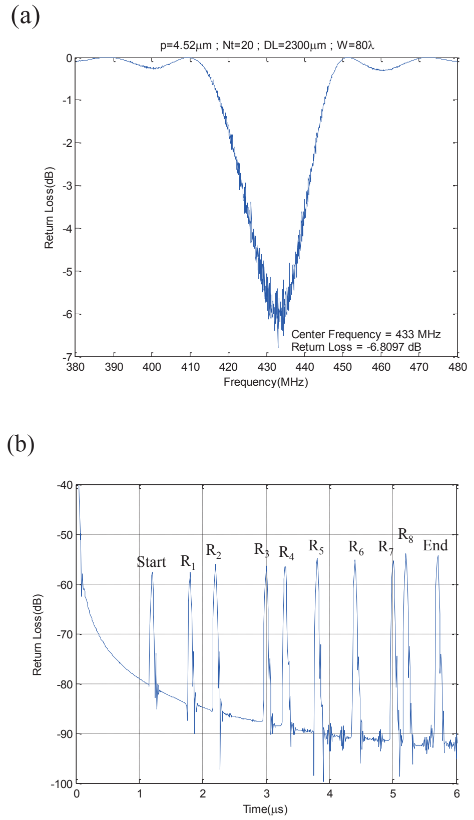

Fig. 2 Return loss calculation by COM model. (a) Frequency domain. (b) Time domain.

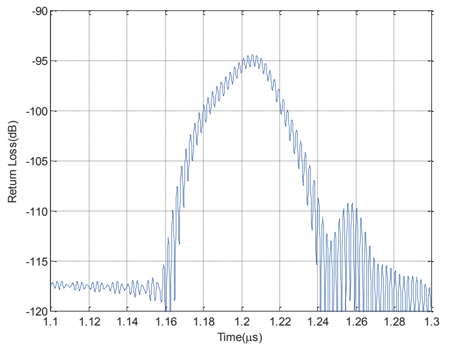

Fig. 3 A wave package for Start reflection in time domain after raising the resolution.

reflector. When the temperature was higher, the delay time became more. TCD was 71.83 ppm/°C. The result compared with the literature which TCD was 71.2 ppm/°C. After the compared, the error was 0.88%. We also measured temperature without raising the time domain resolution. **Fig. 4(b)** shown the relationship between delay time and temperature was not linear.

4. Results

SAW Tag time position encoding case was calculated with COM model for frequency domain and time domain. We filled the same value in frequency domain and used IFFT to get higher resolution and wave package for a peak in time domain. Temperature measurement was shown linearly for delay time which was also filled the same value in frequency domain.

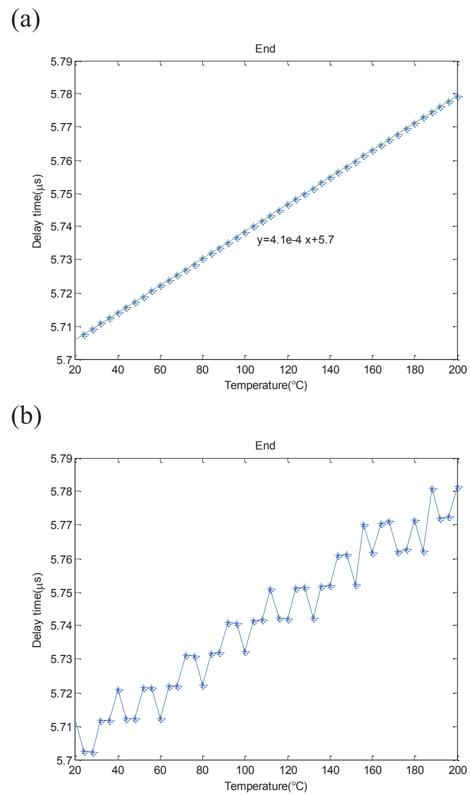

Fig. 4 The relationship between delay time and temperature for End reflector. (a) After filling the same value in frequency domain. (b) Without filling the same value in frequency domain.

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