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Temperature compensation of ball SAW sensor by two-frequency measurement using undersampling
アンダーサンプリングを用いた二周波数測定によるボール SAW センサの温度補償

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1. Introduction

Ball surface acoustic wave (SAW) sensor, that amplify the delay time change due to sensitive film using multiple-roundtrip propagation [1], can realize precise temperature compensation by two-frequency measurement (TFM) [2]. It is expected to realize practical highly sensitive gas sensor [1,3]. For precise phase measurement, we performed a wavelet anlysis of the waveform after oversampling (OS) to Nyquist frequency f_N [1-3] or a digital quadrature detection of down-converted waveform by heterodyne detection [1,4]. However, the measurement systems using an analog-digital converter (ADC) with high sampling rate or heterodyne circuit with multi oscillators and nonlinear devices are expensive. On the other hand, although undersapling (US) less than f_N [5] could simplify TFM system, the applicability of an aliasing response to the sensor is not clear. . In this study, we aim to develop a TFM system using US for practical temperature compensation of bal SAW sensor.

2. Principle of TFM system using US

A block diagram of TFM system using US is shown in Fig.1, where f_1 and f_s are fundamental frequency of the sensor and the sampling frequency of ADC, respectively. A synthesizer synchronously generates a clock of f_s and a burst signal of $6f_1$. The latter is converted to the signals of f_1 and $3f_1$ by frequency dividers, and these signals are combined in phase as the transmission signal. The reflection signal is processed by narrow band-pass filters (BPF) with center frequencies f_c of f_1 or $3f_1$ and recorded by ADCs. In the case of $f_s = 5f_1/4$, signal frequency of $|f_1 - f_s| = f_1/4$ and $|3f_1 - 2f_s| = f_1/2$ are generated by the aliasing. Finally, the wavelet analysis is applied to these frequency components [3].

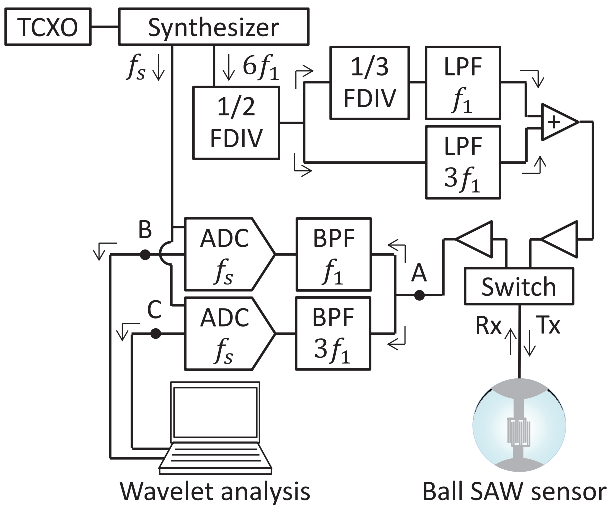

Fig. 1 Block diagram of TFM system of ball SAW sensor using US. f_1 and f_s are fundamental frequency of sensor and sampling frequency of ADC, respectively.

3. Experimental method

A harmonic quartz ball SAW sensor (3.3 mm in diameter, $f_1 = 80$ MHz), coated by sol-gel silica film for trace moisture measurement [3], was measured by a broadband pulsar/receiver and the waveform was recorded using OS (5 GHz, 1024 averaging). To simulate the US at $f_s = 100$ MHz, the data were extracted at intervals of 50 after BPF with 5% width of f_c (4 MHz). The wavelet analyses using Gabor function ($\gamma = 50$) were performed at f_1 or $3f_1$ in the case of OS and at $f_1/4$ or $f_1/2$ in the case of US. The delay time was measured from the difference between those of the 3rd and 7th turns.

4. Results

4.1 Change in waveform by US

The waveforms at positions B and C in Fig.1 were obtained from US of OS waveform A (7th turn, Fig. 2).

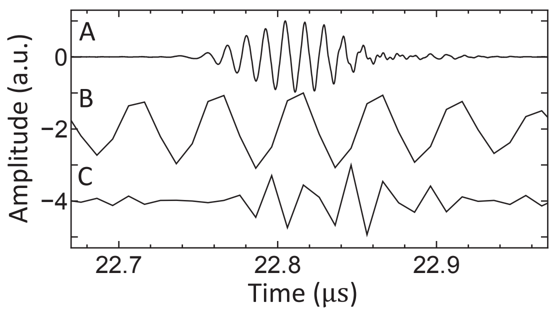

Fig. 2 Waveforms at positions A-C in Fig. 1. A is OS wavefrom (7th turn). B and C are simulated by US.

Corresponding power spectra are shown in Fig. 3. The frequency components of f_1 and $3f_1$ were confirmed in the case of OS (Fig. 3(a)) and those of $f_1/4$ and $f_1/2$ in the case of US (Fig. 3(b)).

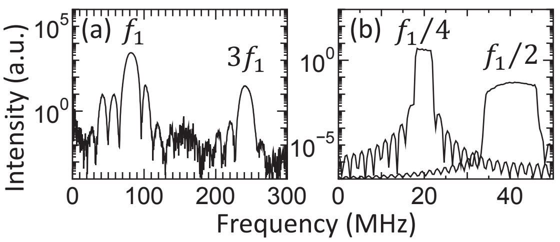

Fig. 3 Power spectra of (a) waveform A and (b) those of B and C, shown in Fig. 2 ($f_1 = 80$ MHz).

4.2 Application to trace moisture measurement

A trace moisture measurement (4-790 nmol/mol) using OS is shown in Fig. 4. In Fig. 4(a), dotted and solid curves represent delay time of f_1 and $3f_1$, respectively. Fig. 4(b) shows the result of subtraction of f_1 data from those of $3f_1$ using a coefficient of 1.0. As a result, the response to the moisture became clear, where the response from 4 nmol/mol to 17 nmol/mol was measured by S/N of 44.8.

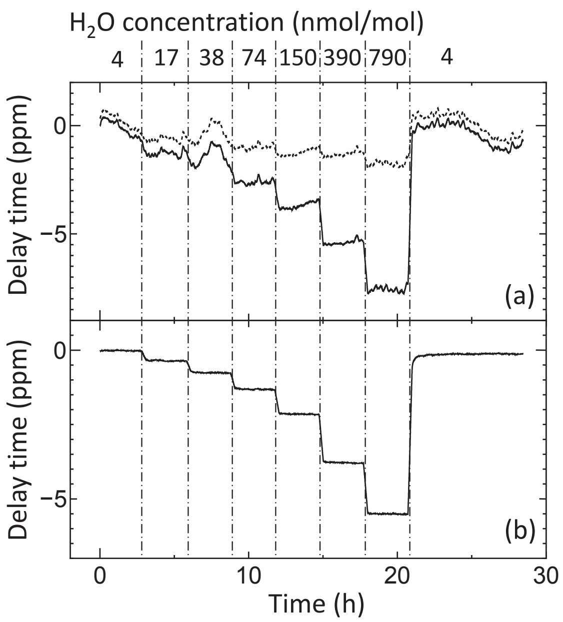

Fig. 4 Temperature compensation with f_1 and $3f_1$ using OS. (a) Solid and dotted curves show outputs of f_1 and $3f_1$, respectively. (b) Compensated output of $3f_1$ subtracted by that of f_1 using coefficient of 1.0.

Next, the result of US is shown in Fig. 5. Dotted and solid curves in Fig. 5(a) represent delay time of $f_1/4$ and $f_1/2$, respectively, where the polarity of $f_1/4$ was inverted due to $f_1 < f_s$. When the data of $f_1/2$ was subtracted by that of $f_1/4$ using a coefficient of -1.5 (Fig. 5(b)), the temperature compensation similar to Fig. 4(b) was obtained, where the response was matched with that of OS by linear function with a correlation coefficient $|R|$ of 0.9999.

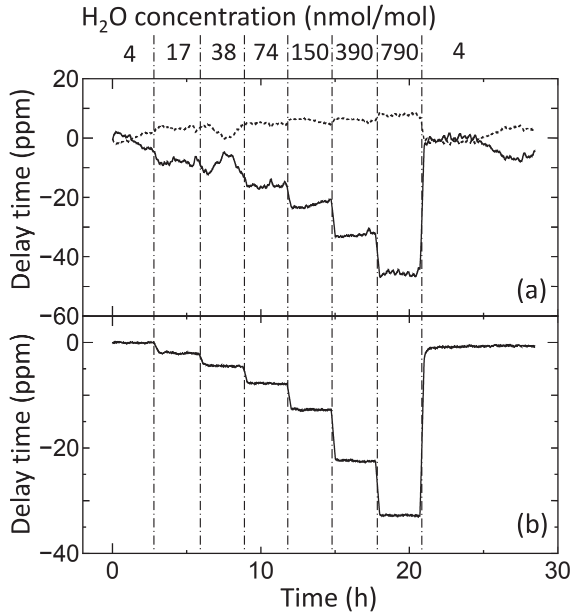

Fig. 5 Temperature compensation with $f_1/4$ and $f_1/2$ using US. (a) Solid and dotted curves show outputs of $f_1/4$ and $f_1/2$, respectively. (b) Compensated output of $f_1/2$ subtracted by that of $f_1/4$ using coefficient of -1.5.

4. Conclusion

It was shown that precise output of a ball surface acoustic wave sensor could be obtained even using undersampling, which was equivalent to that using oversampling. In future, we will develop the circuit shown in Fig.1 and install it in sensor products.

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