Improving Frequency Measurement Accuracy of Fully Digital Phase Detection Quartz Crystal Microbalance Based on Multi-Channel ADC

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Summary*—This paper describes improvement of frequency measurement accuracy of fully digital phase detection QCM, which is a high-precision QCM. In fully digital phase (or frequency) measurement using analog-to-digital converters (ADCs), the equivalent number of bits (ENOB) and sampling frequency of the ADC determine its performance. In this paper, we have verified and confirmed the performance improvement by using multiple ADCs in parallel and increasing ENOB.

***Keywords*—ADC; ENOB; Digital frequency measurement**

I. INTRODUCTION

Quartz crystal microbalances (QCMs) [1], which can detect masses smaller than a few nanograms, are widely used in sensors for bio-metrology, gas measurement, and other applications. In measurement using a QCM, a QCM resonator is generally used to configure a crystal oscillator, and the change in mass is detected as a change in frequency. Therefore, the time resolution and frequency resolution are limited by the gate time of the frequency counter. We proposed a fully digital phase detection QCM (FDPD-QCM) that directly samples the QCM oscillation signal with an analog to digital converter (ADC) and converts the time differential value of the instantaneous phase into a frequency by numerical calculation [2]. The time resolution of the FDPD-QCM is determined by the reciprocal of the ADC sampling frequency, while the frequency resolution is determined by both the equivalent number of bits (ENOB) of the ADC and the sampling frequency. It is not easy to improve the performance of FDPD-QCM because there is a trade-off between the sampling frequency of the ADC and ENOB. In this paper, we confirmed the improvement of ENOB by using multi-channel ADCs in parallel.

II. CONFIGURATION OF FULLY DIGITAL PHASE DETECTION QCM[1]

Fig. 1 shows the configuration of FDPD-QCM. This QCM uses twin quartz sensor fabricated on a single quartz plate. The crystal oscillator with twin sensors shown in Fig. 2 oscillates and its signal is sampled directly to the ADCs. The sampled signal is down-converted and converted to instantaneous phase ϕ_1, ϕ_2 by FPGA or computer processing. The phases ϕ_1 and ϕ_2 of both paths are subtracted, and finally the instantaneous frequency is obtained by time differentiation. The digital down-conversion section uses general orthogonal demodulation as shown in Fig. 3. The most significant feature of FDPD-QCM is that the subtraction process removes not only the temperature characteristics of the crystal resonator but also the phase noise of the clock that drives ADCs.

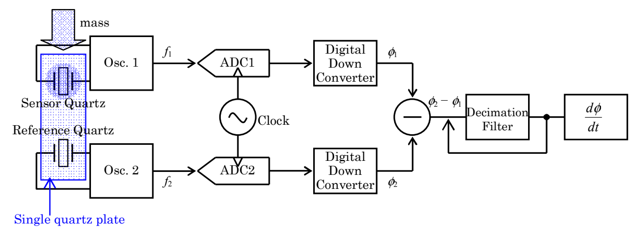

Fig. 1 Configuration of Fully digital phase detection QCM

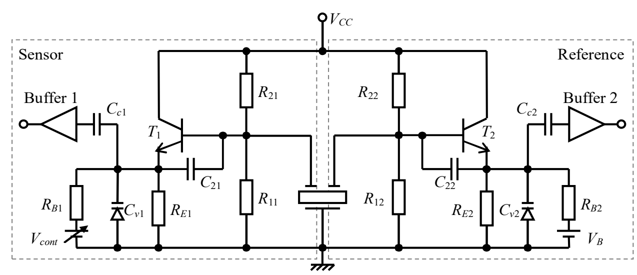

Fig. 2 Oscillator circuit of FDPD-QCM

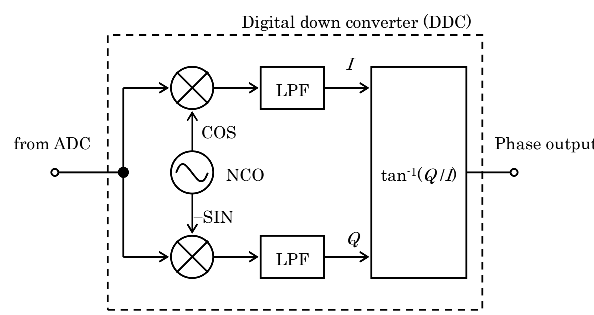

Fig. 3 Configuration of digital down converter

III. ENOB IMPROVEMENT WITH MULTI-CHANNEL ADCs

The amplitude resolution of the ADC is limited by ENOB. For example, the ENOB of a 16-bit, several hundred MHz pipeline ADC is only approximately 12-bits. This means that the performance of the ADC is not being demonstrated due to noise emitted by the ADC itself. In phase noise measurements, the noise floor can be reduced by correlation processing, but this process is a long-time average of the cross spectrum and is not applicable to applications such as QCM, where the frequency varies. In the case of uncorrelated noise, the noise is reduced by parallelization of elements, and if the number of parallel elements is N, the noise is improved by $\sqrt{N}$. Fig. 4 shows the configuration of the proposed FDPD-QCM with parallel ADCs.

IV. EXPERIMENTAL METHODS AND RESULTS

A. *Residual frequency noise of FDPD-QCM*

The residual frequency noise of FDPD-QCM was measured by splitting one signal source output into two branches and inputting them to f_1 and f_2 in Fig. 4. The amplitude of the input signal was set to the full scale range of each ADC, and the frequency was set to a 10 MHz sine wave. The sampling frequency was set to 160 MHz, and the final time resolution was 62.5 µs by passing a one-tenth decimation filter four times. The results in Fig. 5 show a comparison of the residual frequency noise of a normal FDPD-QCM with that of a parallel ADCs. This result is obtained when two ADCs are used in parallel, i.e., ADCs No. 1&3 and ADCs No. 2&4. It can be confirmed that the frequency fluctuation is smaller when the ADCs are in parallel. Fig. 6 shows the phase noise calculated from the phase before frequency conversion; the phase noise is reduced by 3 dB by using two ADCs in parallel, indicating that the ENOB of the ADC is improved by $\sqrt{N}$.

B. *Frequency measurement results by FDPD-QCM*

Fig. 7 shows the measured frequency difference between the two crystal oscillators using the FDPD-QCM. Compared to the results in Fig. 5, the fluctuation of the frequency noise is larger due to the inclusion of the phase noise of the crystal oscillator. The frequency difference between the two crystal oscillators used was about 0.7 Hz, but the parallelization of the ADCs resulted in a smaller frequency fluctuation, indicating that the proposed method is effective.

V. CONCLUSIONS

We examined the improvement of ENOB by parallelizing ADCs in order to improve the frequency measurement accuracy of FDPD-QCM. As a result, we confirmed that ENOB improves in proportion to the square root of the number of parallel ADCs. We will experiments using actual mass measurement in the future.

ACKNOWLEDGMENT

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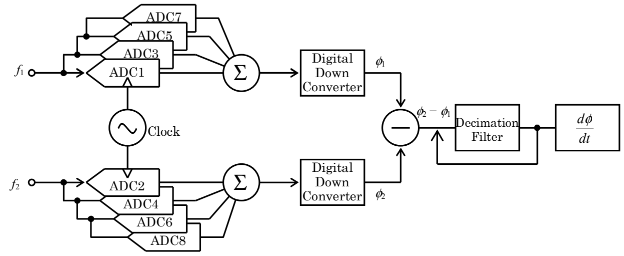

Fig. 4 Parallelization of ADCs

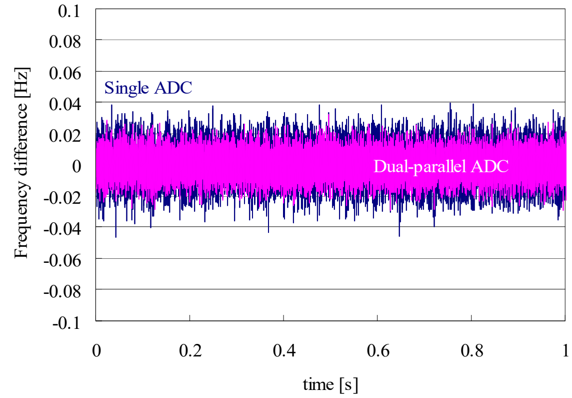

Fig. 5 Comparison of residual frequency noise

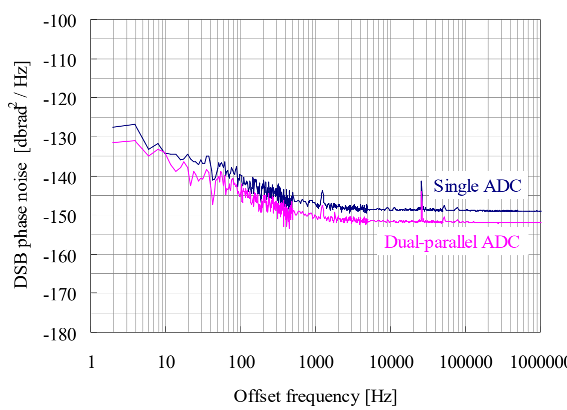

Fig. 6 Comparison of residual phase noise

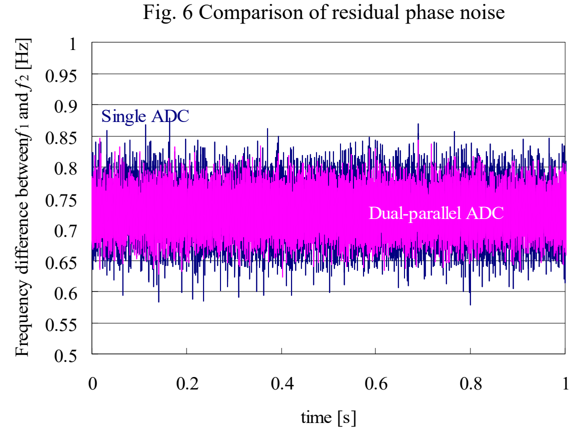

Fig. 7 Frequency difference measurement result

REFERENCES

[1] G. Sauerbrey, " Verwendung von Schwingquarzen zur Wägung dünner Schichten und zur Mikrowägung "Zeitschrift für Physik，Vol.155，Issue 2，pp.206-222

[2] T. Imaike, A. Shirai, " Fully Digital QCM using Twin Quartz Sensor ", 2020 Joint Conference of the IEEE IFCS-ISAF.

[3] T. Imaike, K. Kouchi, " Phase Noise Measurement of RF Devices Using Full Digital Phase Noise Measurement Method ", 2018 IEEE IFCS.