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Applying the Internet of things and quartz crystal microbalance oscillators to quality factor measurement (IoT に対応した QCM 発振器の Q 値の測定

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1. Introduction

The characteristics of liquids like water and lipids can be evaluated by measuring the mass accompanied with variations in viscous characteristics. One way of measuring mass variations is to monitor the variation of the piezoelectric resonator resonance frequency in fluid. Quartz crystal microbalances (QCMs) are frequently used for measuring mass variations on a nanogram scale, and they are advantageous because the resonance frequency variation of quartz crystal resonators is very sensitive[(1)-(4)]. AT-cut crystal resonators are usually used for QCMs because frequency variations in QCMs in AT-cut crystal resonators due to temperature changes are small. AT-cut crystal resonators are very precise. In cases where the main thickness-shear mode is used, AT-cut crystal resonators vibrate parallel to the thickness direction of the quartz crystal[(1)].

The authors carried out a similar measurement using SC-cut quartz crystal resonators. The SC-cut quartz crystal resonators were mainly sensitive to flexural vibration[(4)]. The accuracy of the SC-cut quartz crystal resonator for the temperature characteristic was worse than that of the AT-cut crystal resonators. Applying an oscillator to QCMs can distinguish them from cases in which a network analyzer was applied. QCM oscillators are used to measure the oscillatory frequency of QCMs using only a frequency counter.

In this study, the application of QCM oscillators was regarded as an Internet of things (IoT) technique, and an attempt was made to measure the Q value from phase noise by using a signal source analyzer as well as a frequency counter with oscillatory frequency. Liquid characteristics of QCMs must be delivered over long distances because Wi-Fi, oscillators, and the frequecy converters are used in IoT techniques.

2. Measuring system

Acquired QCM data are sent to the cloud and the server via a low-power wide-area network, which enables analysis and predictions to be carried out remotely. The general IoT (field area) is shown in **Fig. 1**.

When large numbers of QCM sensors are used, they must be installed and operated at low costs. Because of this, IoT devices that can function with low operational management are in demand. An effective approach is to use an energy harvester, such as a solar battery, as a substitute for the galvanic cell. This makes changing the batteries of the QCM devices unnecessary.

The Q value of water was measured with the QCM method and the system shown in **Fig. 2**. This system precisely measures the Q value and the phase noise by using a signal source analyzer. The approximation of the Q value is calculated using

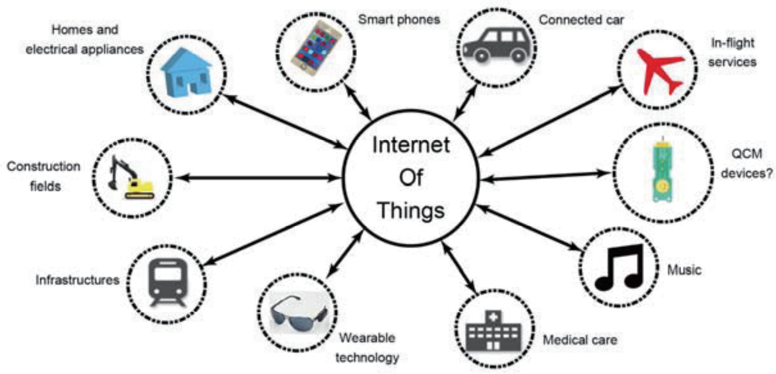

Fig. 1 IoT data are sent to cloud and server via low-power wide-area(LPWA) network.

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$$S_\phi(f)=\alpha\cdot(\upsilon_0/2Q_L)^2/f^3+\beta\cdot(\upsilon_0/2Q_L)^2/f^2+\alpha/f+\beta \quad (1)$$

where α is the 1/f noise factor in the open loop circuit, v_0 is the nominal frequency, Q_L is the loaded Q, and β is white phase noise. The coefficient β is calculated using

$$\beta = GFKT/P_0 \quad (2)$$

where G is the compressed amplifier gain, F is the noise factor of the amplifier, K is Boltzmann's constant, T is the absolute temperature, and P_0 is the carrier power at the amplifier output.

Fig. 3 shows how the IoT might be further applied to the QCM method in the future.

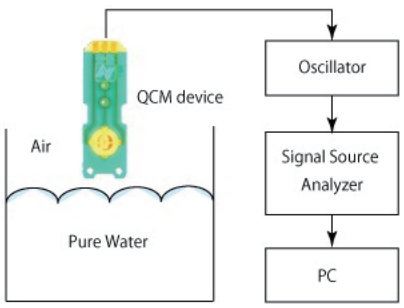

Fig. 2 Method for measuring Q value with QCM in pure water.

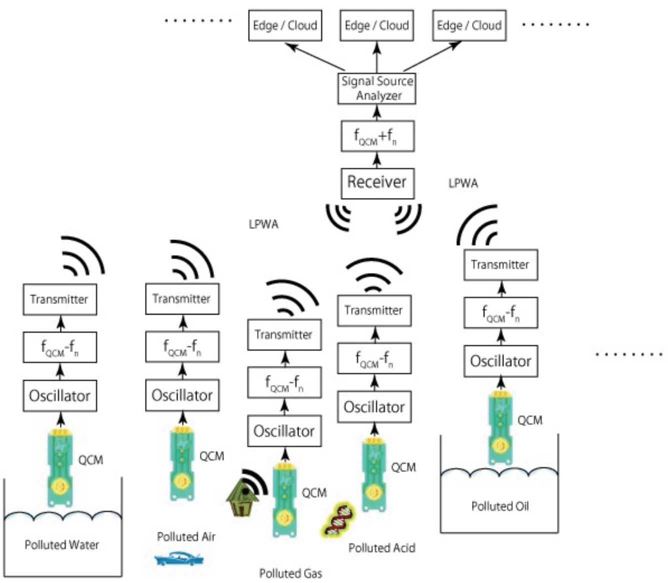

Fig. 3 How IoT might be applied to QCM

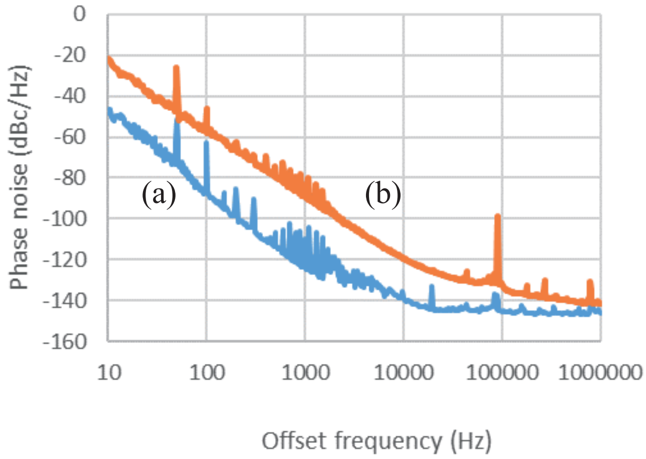

Fig. 4 Phase noise measured with QCM in air (a) and pure water (b)

3. Measurement results

The QCM was kept at 23.6°C in air, as shown in **Fig. 4(a)**, and the phase noise from the signal source analyzer was measured under this condition. **Fig. 4(b)** shows a lower QCM in pure water at a temperature of 23.6°C.

In pure water, phase noise measurements increase offset frequencies to between 10 Hz and 1,000 Hz. The Q value was 1000 in water and 72,000 in air. The equivalent parameters of QCM are expressed in Table 1.

Table 1 Equivalent parameters of QCM

air/pure water	fs(MHz)	L_1(mH)	R1(Ω)
air	30.805	1.03	4
pure water	30.769	0.87	254

4. Conclusion

The Q value was 72,000 in air and 1,000 in pure water. Further development of the frequency converters and oscillators will enable various liquid characteristics to be measured with Q values.

References

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