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# A correction for decrease of discretized ultrasonic signal amplitude by imperfect averaging using external trigger

# 外部トリガを用いた同期加算の不完全性による離散超音波測定信号振幅低下の補正

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## 1. Introduction

The calibration of ultrasonic field parameters (peak-rarefctional acoustic pressure: $p_r$, spatial-peak temporal-average intensity: $I_{spta}$, and spatial-average temporal-average intensity for -6 dB beam area: $I_{sata}$)[1)] has been established at the National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology. In the ultrasonic field parameter calibration, the output voltage of our hydrophone[2)] are synchronous-averaged to improve signal-to-noise ratio. The synchronous-averaging is obtained from an analog-to-digital converter (ADC) using an external trigger signal from the signal generated for driving the ultrasonic transducer under calibration.

In the investigation of the effect of synchronous-averaging on calibration to estimate the uncertainty of the measurement, the amplitude of the hydrophone output signal decreased measurably with increasing ultrasonic frequency due to imperfect synchronization. This article describes a method for correcting this decreased amplitude using an theoretical formula.

## 2. Ultrasonic field parameter calibration

A block diagram of the ultrasonic field parameter calibration system is shown in **Fig. 1**. The ultrasonic transducer used as the ultrasonic projector being calibrated is held in water and driven by the signal generator. The trigger signal from the signal generator is transferred to the ADC and to the frequency counter for synchronous-averaging of the hydrophone output signal and for measuring the ultrasonic pulse repetition period, respectively. The hydrophone is held on a pulse motor stage for scanning a plane perpendicular to the propagating direction of the ultrasonic fields. A computer records the hydrophone output signal, the water temperature, and the pulse repetition period from the ADC, the thermometer, and the frequency counter, respectively, and calculates the ultrasonic field parameters $p_r$, $I_{spta}$, and $I_{sata}$.

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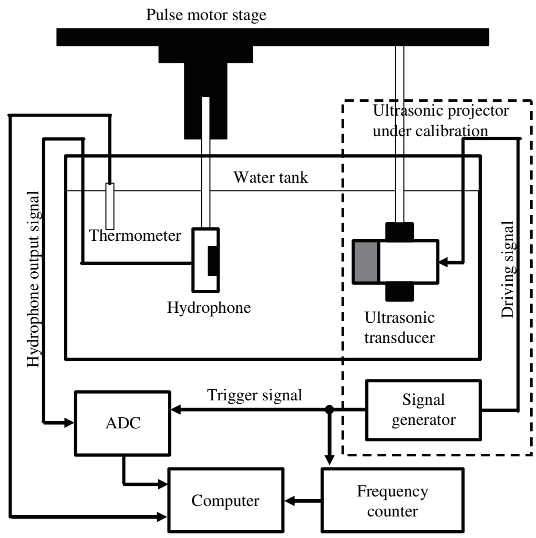


Fig. 1 Block diagram of the ultrasonic field parameter calibration system.

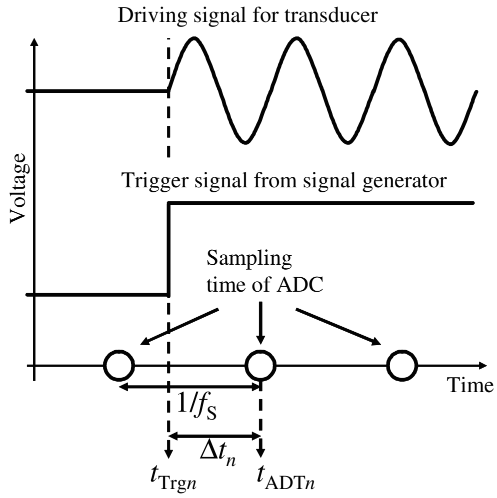


Fig. 2 Temporal difference $\Delta t_n$ between when the ultrasonic transducer starts to be driven $t_{Trgn}$ and when the ADC is triggered $t_{ADTn}$.

## 3. Estimation of decreased amplitude

When a hydrophone output signal is acquired for synchronous-averaging in the ADC, the ADC checks the voltage of the trigger signal discretely with sampling frequency $f_S$ as shown in **Fig. 2**. Therefore, the temporal difference $\Delta t_n$ for the $n$th acquired signal between when the ultrasonic transducer starts to be driven, $t_{Trgn}$, and when the ADC is triggered, $t_{ADTn}$, occurs in the range of $0 \leq \Delta t_n < 1/f_S$. The amplitude decrease of the discretized hydrophone output signal due to the temporal difference $\Delta t_n$ in the synchronous-averaging is estimated theoretically.

When a sinusoidal wave with amplitude $A$ and frequency $f$ is treated as a synchronous-averaged ultrasonic signal with number of averaging $N$, the instantaneous signal obtained by the synchronous-averaging $g_{AVE}(t)$ is

$$g_{\mathrm{AVE}}(t) = \frac{A}{N}\sum_{n=1}^{N}\cos\{2\pi f\left(t+\Delta t_{\mathrm{n}}\right)\}. \quad (1)$$

Based on eq. (1), the amplitude $A_{AVE}$ of $g_{AVE}(t)$ is

$$A_{\mathrm{AVE}} = \sqrt{\left(\frac{A}{N}\sum_{n=1}^{N}\cos\left(2\pi f\Delta t_n\right)\right)^2 + \left(\frac{A}{N}\sum_{n=1}^{N}\sin\left(2\pi f\Delta t_n\right)\right)^2}. \quad (2)$$

The two terms inside pairs of brackets in eq. (2) represent arithmetic means of $A\cos(2\pi f\Delta t_n)$ and $A\sin(2\pi f\Delta t_n)$. Therefore, these two terms can be estimated as statistical expected values when $N$ is sufficiently large. Generally, because the period of a trigger signal (i.e., that of a pulse repetition period of a ultrasonic signal) is much longer than the sampling period of the ADC, $\Delta t_n$ can be assumed to be a random variable uniformly distributed on $0 \leq \Delta t_n < 1/f_S$ unless the pulse repetition period of the ultrasonic signal is exactly equal to an integer multiple of the sampling period of the ADC. Therefore, the estimation values of the decreased amplitude $A_E$ and the relative decrease of the amplitude (decrease ratio) $K_{AVE}$ are derived by replacing the aforementioned two terms in eq.(2) by the statistical expected values as follows:

$$A_{\mathrm{E}} = \sqrt{\left(Af_{\mathrm{S}}\int_0^{1/f_{\mathrm{S}}}\cos\left(2\pi f\Delta t_n\right)d\Delta t_n\right)^2 + \left(Af_{\mathrm{S}}\int_0^{1/f_{\mathrm{S}}}\sin\left(2\pi f\Delta t_n\right)d\Delta t_n\right)^2}. \quad (3)$$

$$K_{\mathrm{AVE}} = \frac{A_{\mathrm{E}}}{A} = \frac{\sin\left(\pi f / f_{\mathrm{S}}\right)}{\pi f / f_{\mathrm{S}}}. \quad (4)$$

## 4. Results and discussions

We measured the decreased amplitude by the synchronous-averaging using the following method. The amplitude voltage of the synchronous-averaged hydrophone output signal for a certain ultrasonic frequency $f$ and number of synchronous-averaging $N$ was obtained using fast Fourier transform from. The hydrophone was held 270 mm from ultrasonic transducers with diameters of 13 mm for the 5 MHz signal and 6.4 mm for 10 MHz and 15 MHz signals. The signal for driving the transducer was a tone burst wave with a pulse duration of 20 μs and a pulse repetition period of 2 ms. The sampling frequency of the ADC was 102.4 MHz.

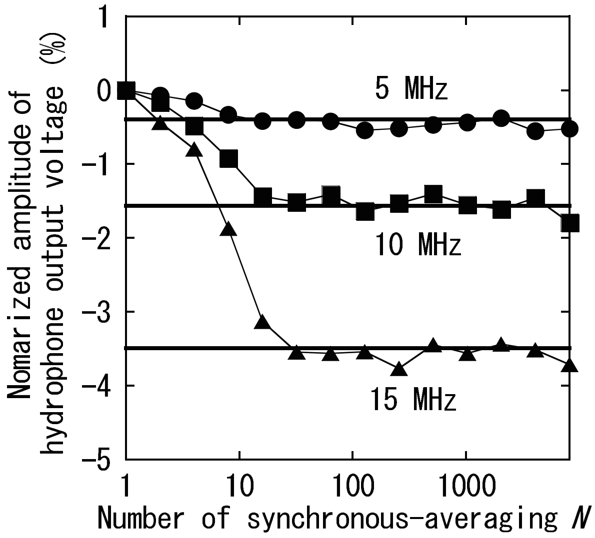


Fig. 3 Measurement results of measuring decrease of hydrophone output signal with synchronous-averaging number.

The resulting measured amplitude versus synchronous-averaging number is plotted in **Fig. 3**. The plotted amplitudes are normalized by that for $N = 1$. The straight solid lines in Fig. 3 are the decreased ratios $K_{AVE} - 1$ calculated using eq. (4) for each frequency. The measured amplitude decrease agrees approximately with theoretically estimated values for $N$ greater than or equal to 32. Therefore, we have confirmed that the decrease of discretized ultrasonic signal amplitude by imperfect synchronous-averaging using an external trigger can be corrected using $K_{AVE}$ defined in eq. (4). We intend to continue the investigation to obtain an accurate uncertainty estimation of $K_{AVE}$. Furthermore, we would improve the calibration system not required the correction.

## References


1. IEC 62127-1:2007.
2. M. Yoshioka: Sansoken Keiryo Hyojun Houkoku **5** (2006) 189 [in Japanese].