# Novel Light-shift Measurement Method with Multiple Photo Detectors for Gas-cell Based Atomic Clocks

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***Summary*— A simple light-shift measurement method using multiple photodetectors (PDs) suitable for chip-scale atomic clocks (CSACs) and miniature atomic clocks (MACs) was proposed. This method can be used with at least two photodetectors in real-time operations. To increase the long-term frequency stabilities of CSACs and MACs, the proposed method can be used as a zero light shift detector for active light shift stabilization [1].**

***Keywords—light-shift; multiple photodetectors; chip-scale atomic clocks (CSACs); miniature atomic clocks (MACs)***

## I. Introduction

Compact gas-cell based atomic clocks, such as chip-scale atomic clocks (CSACs) and miniature atomic clocks (MACs), are widely used in the precise time and frequency applications. In these clocks, better long-term frequency stability is required to increase performance of the time stamp precision of sensed data, synchronization of systems, GNSS jamming and spoofing robustness, and so on.

for time stamping and keeping clocks .

In these clocks, the light source to excite and detect an atomic resonance is typically parallelized laser beam collimated from a semiconductor laser. The atomic resonance can be observed by detecting the transmitted light through the gas-cell. A conventional photo detection method is capturing the transmitted light by a large size photodiode to increase a signal-to-noise (S/N) ratio. It is well known that the collimated parallel beam has a Gaussian-shaped intensity distribution in the plane perpendicular to the beam axis, therefore, the captured light signal is the superimposed result of interactions between different laser intensities of the laser beam and alkali atoms.

Because the conventional photodetection of the propagated light through the alkali gas cell uses a single large-size photodiode to capture the entire light beam signal, the detected signal is the superimposed result of interactions between different laser intensities of the laser beam and atoms.

In this paper, we propose a light-shift measurement method that can observe multiple light intensity characteristics of atomic resonances simultaneously using multiple separated photodetectors. Here, we present the measurement results of the light-shift characteristics using the proposed method.

## II. Light Shift Measurement System

To demonstrate the proposed method, we used a 16-channel photodiode array (S15158, Hamamatsu Photonics K.K.) with each detection area of 0.7 × 2.0 mm and a gap length of 0.1 mm as the separated multiple photodetectors (PDs). Figure 1 shows the schematics of the light-shift measurement system with multiple PDs. A single-mode vertical-cavity surface-emitting laser (VCSEL) with a wavelength of 895 nm tuned on the Cs-$D_1$ line was used as the light source. The output laser beam was collimated to a 6.4 mm diameter and circularly polarized to excite coherent population trapping (CPT) resonances. Because the purpose of this study is to confirm the principle of our method, each PD signal of the multiple PDs was measured sequentially by the signal switcher, and the gas-cell was a light length of 18.5 mm for easier measurements.

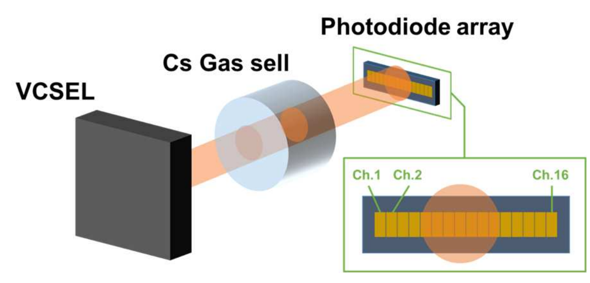


Fig. 1 Schematics of the light-shift measurement system

## III. Measurement Results

Figure 2 shows the light intensity distribution of the laser beam measured without a gas cell. Channel 8 had the highest power intensity, indicating that the beam center was located near this channel. Clearly, the distribution pattern had a Gaussian shape. Because the light shift (AC stark shift) effect is proportional to the light intensity, we can observe CPT resonances with different frequency shifts on each PD channel. The observed CPT resonances of channels 5, 6, and 8, for which the light intensities were different by more than twice each other, are shown in Fig. 3. The CPT amplitudes were approximately proportional to the light intensity; thus, the measured amplitudes differed. The frequency detuning showed a different frequency from the CPT resonance frequency of Channel 8. The figure also shows that both resonance frequencies of channels 5 and 6 were slightly shifted towards lower frequencies because of the light shift effect.

Figure 4 shows the light shift characteristics measured using the proposed method and the traditional method with changing natural density (ND) filters. Because both fit lines were relatively the same, it was clear that the proposed method could observe CPT resonances with different light intensity characteristics. The light shift coefficients, which are the slope values of the fit lines, differed by approximately 19%. Because we assumed that this was caused by the laser not being a perfect parallel beam, the diffusion of the laser beam changed the slope of the light-shift measurements. In a future work, we will evaluate the diffusion effect of the laser beam.

## IV. Conclusions

We propose and demonstrate a simple light-shift measurement method using multiple PDs suitable for CSACs and MACs. The method can be used with at least two photodetectors and can be operated in real time because multiple atomic resonances can be observed simultaneously in running atomic clocks. To increase the long-term frequency stabilities of CSACs and MACs, the proposed method can be used as a zero-light shift detector for active light shift stabilization [1].

## References


[1] V. Shah, P. D. D. Schwindt, V. Gerginov, S. Knappe, L. Hollberg and J. Kitching, "Active light shift stabilization in modulated CPT clocks.," 2006 IEEE International Frequency Control Symposium and Exposition, 2006, pp. 699-701, doi: 10.1109/FREQ.2006.275473.


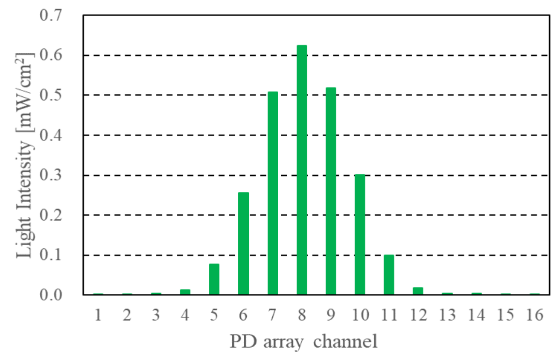


Fig. 2 Detected light intensity of each photodiode array channel

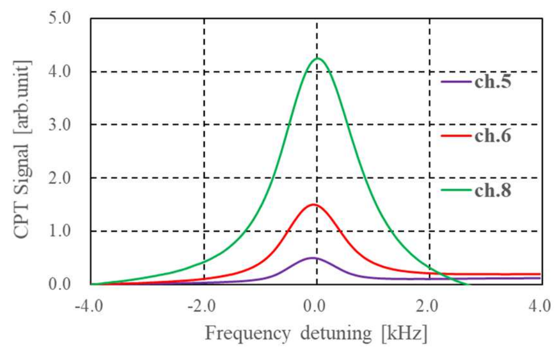


Fig. 3 CPT resonances observed by different photodiode channels (5, 6, and 8)

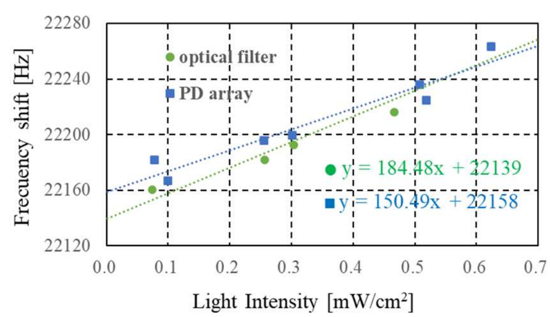


Fig. 4 Light shift characteristics plotted using the measured values of photodiode channels 5 to 11 and using the measured value of photodiode channel 8 with changing ND filters.