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Laser-Pumped Cs Gas-Cell Type Atomic Clock for VLBI

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Abstract

A hydrogen maser is generally used as a local clock of a VLBI system, where very high frequency stability is required. No other atomic clocks such as Cs beam type and Rb gas-cell type clocks were sufficiently stable in the short- and medium-term time scale, which is used in VLBI measurements. Recently, we have developed a gas-cell type atomic clock using Cs gas and a semiconductor laser as a light source. It is desktop size and much smaller than conventional hydrogen masers, but it has a stability of 7×10^{-13} at 1 second reaching a flicker floor of 2.5×10^{-14} at 1000 seconds. When fluctuation due to the atmosphere in actual VLBI measurements is considered, this stability is good enough for most of the VLBI measurements using S-band and X-band. A preliminary results of VLBI experiments at X-band (8 GHz) using the atomic clock developed in this study is discussed.

1. Introduction

Atomic clocks are often used when a high frequency stability is required in measurements such as VLBI. Among commercially available various types of atomic clocks, a hydrogen maser is commonly used in VLBI, but it is large and expensive compared to other types of atomic clocks. A Cs beam-type atomic clock with a magnetic state selector has a high stability when averaged for a long time, but its stability in the time range generally used in VLBI is about two orders of magnitude less stable than that of the hydrogen maser. A Rb gas-cell type atomic clock is small and inexpensive, but its stability is not better than that of a high-performance Cs beam type atomic clock, and it shows a drift in frequency in a long term. Thus, only the hydrogen maser could be used in VLBI measurements.

There have been a number of studies on the gas-cell type atomic clock with laser pumping. It is theoretically known that the stability of this type of atomic clock becomes better if the Rb plasma lamp of the Rb gas-cell type atomic clock is replaced by a laser light source [1, 2, 3, 4]. We have been studying this type of atomic clock using Cs instead of Rb, and developed a desk-top size laser-pumped Cs gas-cell type atomic clock having a stability between that of the hydrogen maser and that of the conventional Rb gas-cell type atomic clock [5]. In this paper, this new type of atomic clock is briefly introduced and a preliminary application of this atomic clock to VLBI measurements is discussed.

2. LD-pumped Cs gas-cell type atomic clock

Figure 1 is a block diagram of the developed atomic clock. Light from the frequency-stabilized LD is put into the physics unit containing a Cs gas-cell in a TE011-mode 9.192-GHz resonance cavity. The light passing through the Cs gas-cell is detected by the photodetector 1 (PD1). Part of the LD light reflected by a beam splitter is put through a reference cell without microwave resonance cavity and detected by the photodetector 2 (PD2). The output of the PD2 is subtracted from that of the PD1 to reduce noise caused by LD amplitude and frequency fluctuations [4]. Cesium absorbs the maximum amount of light when the microwave injected from the synthesizer resonates at the frequency corresponding to the hyperfine transition within the Cs ground state. The microwave synthesizer output frequency is locked to the Cs transition frequency using a voltage-controlled quartz oscillator (VCXO).

Figure 2 is the photograph of the atomic clock developed in this study. Since some components are not designed for this specific equipment, it is still contained in two cabinets; one contains the

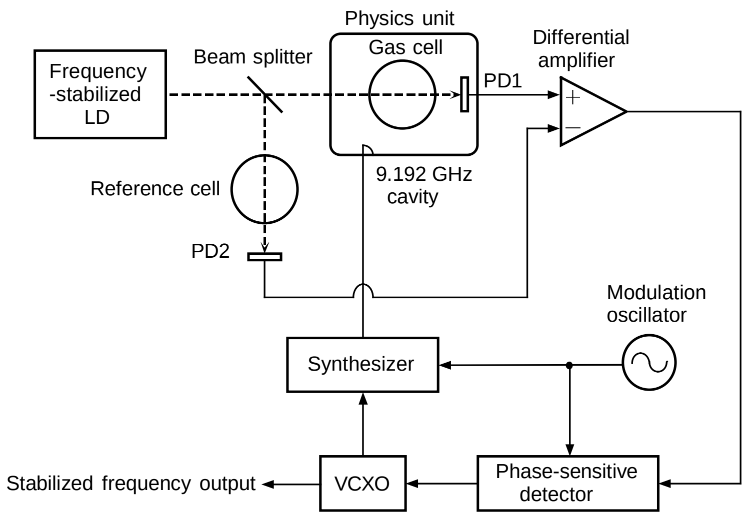

Figure 1. Block diagram of the developed atomic clock. Electrical connections and optical paths are indicated by solid and broken lines, respectively.

Figure 2. Photograph of the developed atomic clock. The 1-MW 7”-high module on the bottom contains the physics unit coupled with the light frequency-stabilized LD and most of the electronic circuits. The 1-MW 5”-high module on the top contains the frequency-adjustment digital switch, a CPU, and power supplies.

physics unit coupled with the light frequency-stabilized LD, a microwave synthesizer and electronic circuits, and the other contains a frequency adjustment digital switch, a CPU, and power supplies. The laser frequency is automatically locked to a specific saturated-absorption line of Cs and the gas-cell is heated up to the temperature that gives the best frequency stability.

The stability of the atomic clock was measured in comparison to a hydrogen maser (Anritsu RH401A). The dual mixer time difference method was used for an averaging time of 100 sec or less, and the phase comparison method was used for an averaging time longer than 100 sec. The results are shown in Fig. 3 along with the characteristics of some commercially available atomic clocks. It shows that this atomic clock has unique characteristics between the hydrogen maser and the Cs beam type atomic clock. Up to 3×10^3 sec, it has at least one order of magnitude better stability than a commercial high-performance Cs beam type atomic clock with a magnetic state selector (Agilent 5071A, Op. 001). The stability of the atomic clock developed in this study reaches the flicker floor of 2.5×10^{-14} at about 1,000 sec. A study is in progress to clarify what determines the short-term stability and flicker floor of this atomic clock. We have not yet been able to obtain a reliable data of stability for an averaging time longer than 1×10^4 sec, but since there seems to be no obvious drift of the frequency, we believe that the flicker floor at low 10^{-14} will be extended to a longer averaging time by a future study.

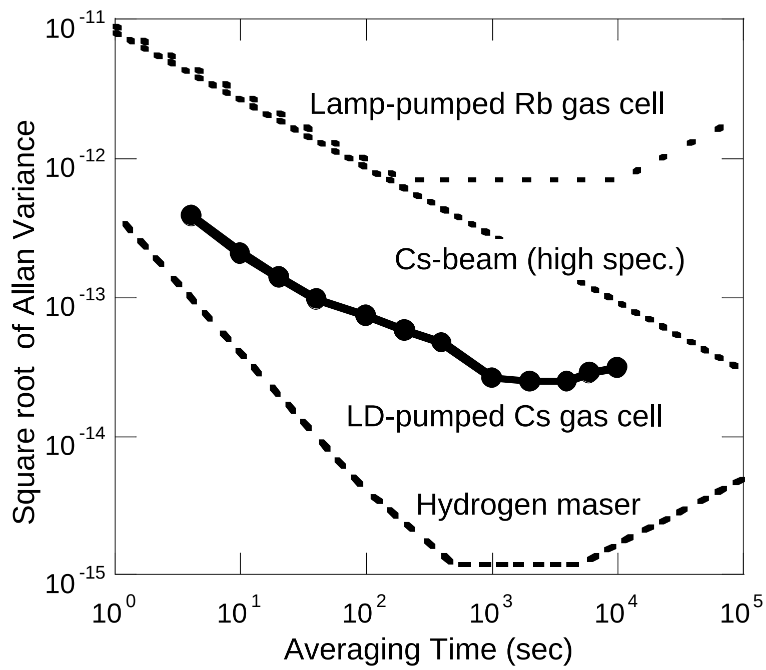

Figure 3. Measured stability of developed atomic clock and characteristics of various commercially available atomic clocks (typical Rb gas-cell type, high-performance Cs beam type (Agilent 5071A Option 001), and hydrogen maser (Anritsu RH401A)). The developed atomic clock was evaluated with reference to the hydrogen maser.

3. Application to VLBI Measurements

In VLBI measurements, local clocks must have a sufficiently high stability that gives satisfactory coherence at the measurement frequency for an averaging time of a specific measurement [6]. Figure 4 shows the calculated coherence assuming the stability of the clock developed in this study as shown in Fig. 3. The coherence was calculated for the measurements frequency of 2, 8 and 22 GHz. If the coherence better than 0.8 is assumed to be required for the VLBI measurements, the stability of the clock developed in this study is good enough for measurements at 2 and 8 GHz in the calculated averaging time range, and at 22 GHz, the averaging time would be limited to up to 300 sec.

Another factor that frequently limits the actual accuracy of VLBI measurements is the fluctuation due to water vapor in the atmosphere. It has been observed that the magnitude of such fluctuation changes depending on weather. The atmospheric fluctuation was measured, and the square root of Allan variance was deduced [7]. It shows that, for the averaging time between 10 and 100 sec, the square root of Allan variance is mostly in the range of 1×10^{-13} to 5×10^{-13} depending on the weather conditions. In the averaging time range longer than 100 sec, the fluctuation is white noise and the square root of Allan variance decreases as the averaging time increases. Therefore, if the clock developed in this study is used in VLBI measurements at the frequencies and the averaging time range shown in Fig. 3, the limiting factor of the VLBI measurement accuracy is likely to be the fluctuation due to the atmosphere. That is to say, the stability of the clock developed in this study is good enough and does not affect the accuracy in most of the VLBI measurement.

In February 2001, a preliminary VLBI measurements was carried out using the atomic clock under study at Aira site of the Geographical Survey Institute, Japan. The results of analyses are shown at the following web site, `http://vldb.gsi.go.jp/sokuchi/vlbi/english/main.html` . It indicates that each independent measurement was carried out with a reasonable accuracy.
However, there was a slow variation of atomic clock frequency which was later found to be due to temperature variation of the room where the atomic clock was installed. This lead to some additional errors in the analyses, as the final result of geodetic measurements is obtained by averaging many observation using different sources. So the experimental results showed that the atomic clock developed in this study could be used in place of a hydrogen maser either by a further suppression of the temperature dependence of the output frequency or by stabilizing the ambient temperature of the atomic clock.

4. Conclusions

A laser-pumped Cs gas-cell type atomic clock with a high stability has been developed. It has a stability of 7×10^{-14} at 100 sec with a flicker floor of 2.5×10^{-14} at around 1000 sec. This stability is better than those of conventional commercial Rb gas-cell type atomic clocks and Cs beam type atomic clocks with a magnetic state selector in the averaging time range measured in this study (from 4 sec to 10,000 sec). A VLBI measurement was carried out using the atomic clock developed in this study, and it became clear that this clock could be used in place of a hydrogen maser if output frequency variation due to ambient temperature is suppressed.

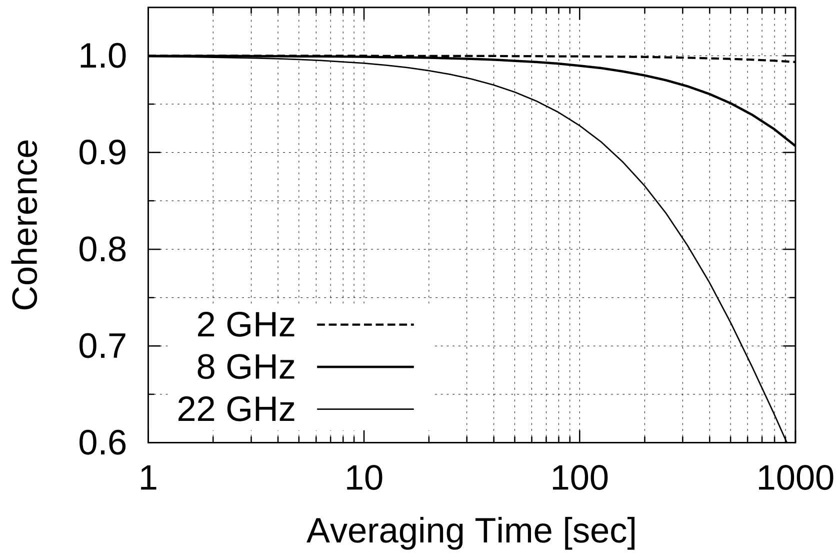

Figure 4. Coherence calculated by assuming the stability obtained for the atomic clock developed in this study.

5. Acknowledgements

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