Advances of Chip-Scale Atomic Clock in Peking University in 2020

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***Abstract*—Chip-scale atomic clock (CSAC) has the advantages of small volume, low power consumption and high frequency stability. We made improvements to the physics package and control algorithm of our CSAC in the last year, which reduces the power consumption of PP and improves the frequency stability of CSAC. Meanwhile, the 1 pulse per second (1PPS) time error of CSAC is also minimized. The total power consumption of PP is about 80 mW, and 1PPS time error keeps less than 20 ns in 3 minutes.**

Keywords—chip-scale atomic clocks; CSAC; frequency reference; physics package

I. Introduction

Since the idea of CSAC based on coherent population trapping (CPT) transition was proposed [1], CSAC is widely used due to its small volume, low power consumption and high accuracy, especially in situations where power supply by battery [2, 3]. Micro-Positioning, Navigation and Timing (M-PNT), modern communication, transportation, network synchronization system and finance are such applications that needs CSAC [4]. One goal of CSAC is to reduce power consumption. Researchers proposed many methods to achieve this goal, such as suspension structure, vacuum packaging [5]. Another goal of CSAC is to reduce volume. Micro-Electro-Mechanical System (MEMS) was used to fulfill this requirement. The traditional glass vapor cell is replaced by MEMS cell for a smaller volume more than ten years ago [6]. However, the most critical target of CSAC is the frequency performance and timing accuracy. The frequency output of CSAC is influenced by buffer gas, temperature accuracy and magnetic stability [7].

In order to reduce the power consumption and improve the frequency performance and timing accuracy of CSAC, we made improvements to the physics package and control algorithm of our CSAC in the last year, which reduces the power consumption of physics package and improve the frequency stability of CSAC. Besides, the 1 pulse per second (1PPS) time error of CSAC is also minimized. The total power consumption of physics package is about 80 mW, and 1PPS time error keeps less than 20 ns in 3 minutes.

II. Methods

In order to meet the power and 1PPS timing accuracy requirements of M-PNT, we made some improvements to our CSAC. Our CSAC system is illustrated in Fig. 1 [8]. The microcontroller MSP430 is the key of control circuits that provides high accuracy current and temperature control for vertical cavity surface emitting laser (VCSEL). The CPT signal is detected by a PD and the data is processed by MSP430. An error signal is used to adjust the output frequency of temperature compensated crystal oscillator (TCXO).

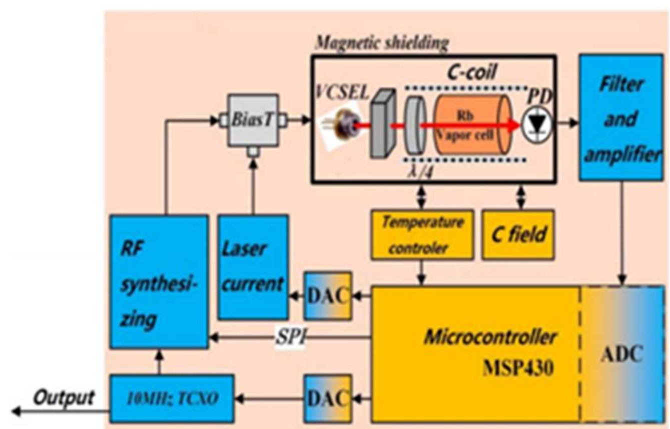

Figure. 1. Schematic of CSAC system

Based on Fig. 1, we optimized the algorithm of 1PPS generation. In order to increase the CSAC insensibility to ambient temperature change, gold-tin eutectic bonding [9, 10] is introduced to physics package for vacuum packaging. Eutectic bonding has the advantage of relative low bonding temperature (~280 ℃), which guarantees the intact of components like photodiode during the bonding process. As shown in Fig. 2, the physics package is at a very high vacuum background (~ 10^{-7} Torr). Then the gold-tin preform melts and bonds leadless chip carrier (LCC) and shell together. The getter is activated at the same time to absorb gases leaking from the sealing surface. We conducted fine leak test to physics package after eutectic bonding. The leakage rate of all 10 physics packages is measured to be less than 4.0×10^{-10} Pa·m^3/s. This is vital for vacuum maintenance.

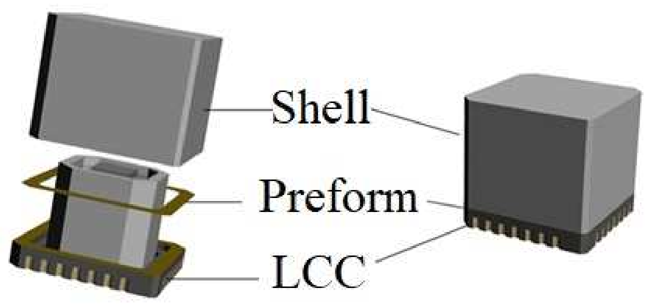

Fig. 2. Vacuum packaging

With the improvements of physics package and algorithm of 1PPS generation, the power consumption of physics package is reduced to about 80 mW. Fig. 3 shows the time error measurement experiment setup for CSAC 1PPS. The 1PPS signal from GPS receiver is divided into two. One inputs as the reference 1PPS signal for 53230A. Another is for the synchronization and discipline of CSAC 1PPS before turning off the switch. 53230A measures the 1PPS time error between GPS and CSAC.

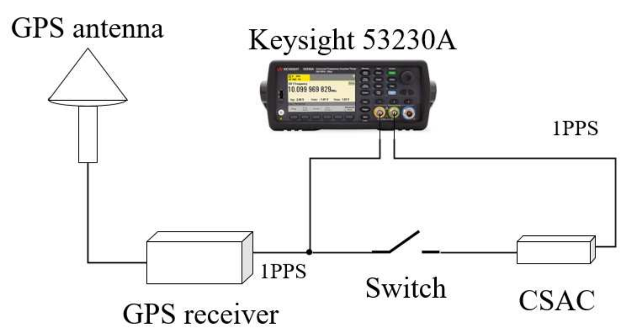

Figure. 3. Experiment setup for time error measurement.

III. RESULTS

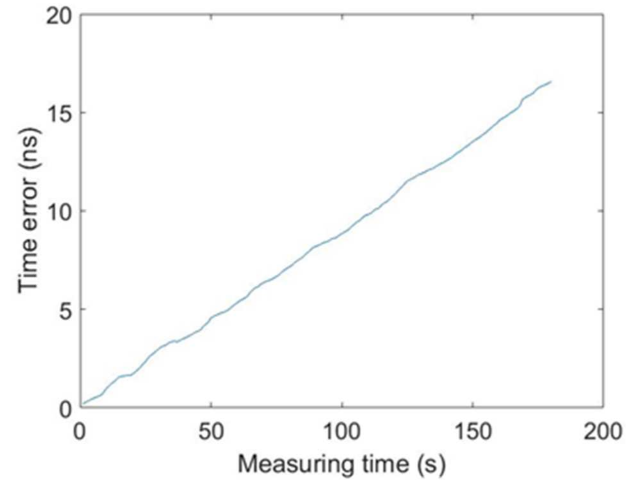

Figure. 4. Time error of CSAC 1PPS

The error is 16.5 ns in a 3-minute measurement as illustrated in Fig. 4. The leakage rate of all 10 physics packages is measured to be less than 4.0×10^{-10} Pa·m^3/s. And the power consumption of physics package is about 80 mW.

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