Developing an electrical model of chip-scale Cesium atomic clock

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Motivation:

Telemedicine is one of the future trends of the medical field. Telemedicine system provides healthcare for patients who are physically challenged or located in remote regions. When those who live in a remote area encounter an accident and need to undergo a surgery in the area where medical service cannot be accessed easily, the remote surgery operated by a robotic arm can save lives.

To carry out precise surgical operations remotely, a low-latency communication system with large coverage area is necessary. The sixth-generation (6G) communication system includes a large amount of low earth orbit (LEO) satellites, which is namely the satellite constellation, can transmit or receive signals to or from the regions that are out of the coverage area of 3G, 4G, or traditional communication satellites.

The speed of low earth orbit (LEO) satellites is considerably high, so it's necessary for a LEO satellite to equip a high accuracy and high stability clock as the reference timing. A cesium clock, which is exploited as the standard timing reference, is to be widely deployed in a LEO satellite. Nevertheless, the form factor of a classic cesium clock in a traditional satellite is too bulky and the power consumption is too high. In this poster, we would like to build up an electrical model of the chip-scale atomic clock, aiming to size reduction and decrease of power consumption, enabling ubiquitous deployment of chip-scale Cesium atomic clock.

Communication satellites:

LEO (Low Earth Orbit):

Height: 160 ~ 2000 km

LEO satellites have Low-latency but small coverage area for each satellite. LEO satellites are smaller in size and orbit near the earth, so the cost of manufacture and launching are lower.

MEO (Medium Earth Orbit):

Height: 2000 ~ 35, 786 km

MEO satellites provide fiber-like performance to the areas hard to place a fiber. It's used for GPS and other navigation applications.

GEO (Geostationary Earth Orbit):

Height: 35, 786 km

GEO satellites move at the same velocity and direction as the earth's rotation, so they stay at a fixed position in the sky. Devices don't need to move their antennas to track the satellites.

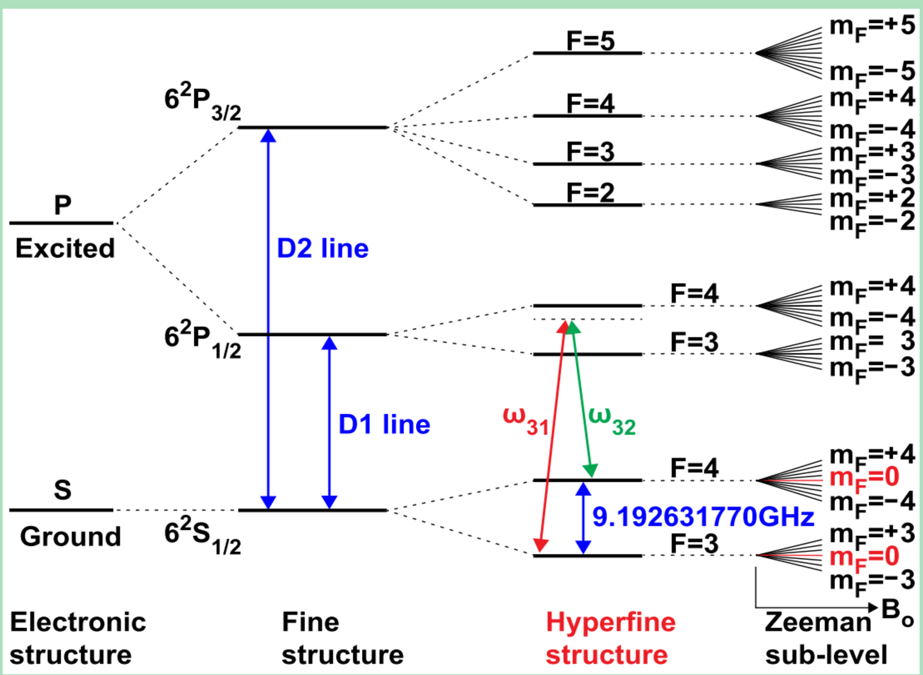

Figure 1. Cs atom energy level

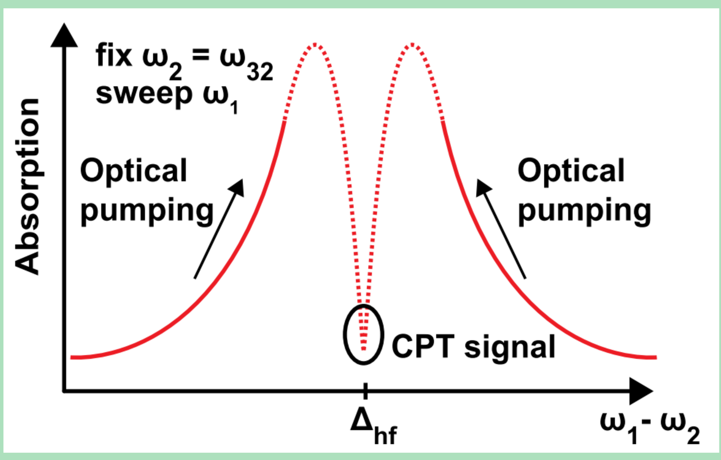

Figure 2. Frequency difference of light field—absorption curve

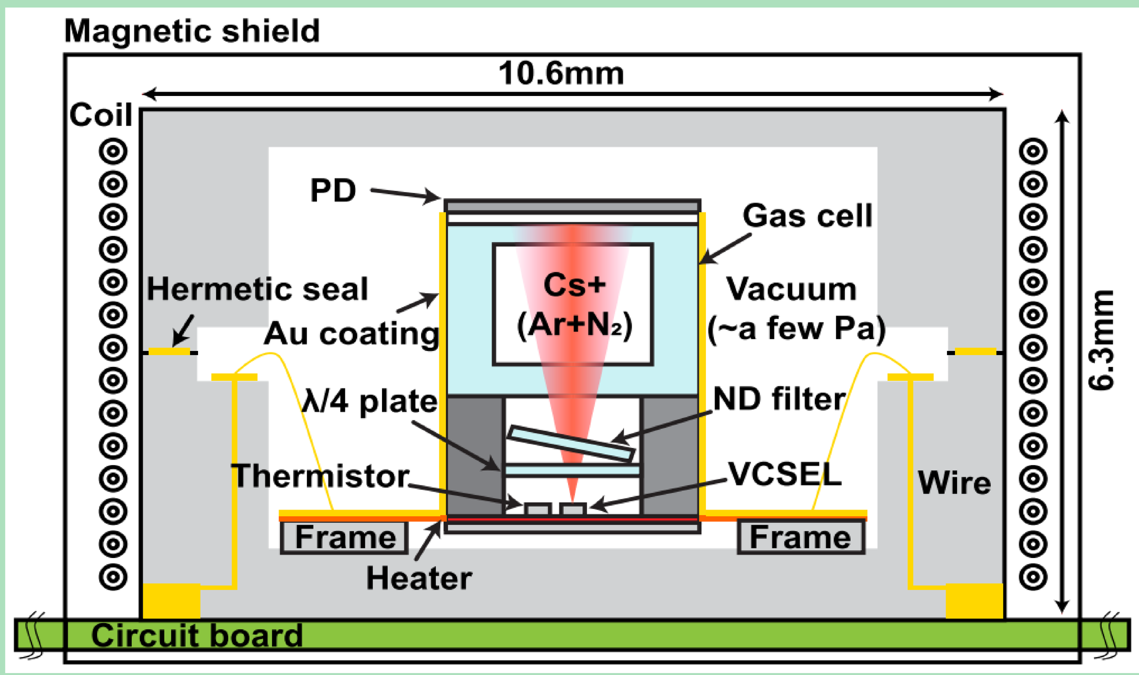

Figure 4. Quantum package

The definition of the second:

The second is the duration of 9, 192, 631, 770 of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

CPT (coherent population trapping):

The electron in an atom can absorb light and jump to an excited state when the light field matches the transition frequency, like the ω_{31} and ω_{32} in Figure 1. However, for alkali-metal atoms, when two light fields are applied to the atom simultaneously, and the frequency difference between the two fields exactly matches the microwave transition frequency, the atom will be trapped in a "dark state", so it cannot absorb light and be excited.

If we can apply the two light fields to as cesium atom cell and detect the absorption, we can lock the frequency at the frequency difference $\omega_{31} - \omega_{32}$ when CPT phenomenon occurs.

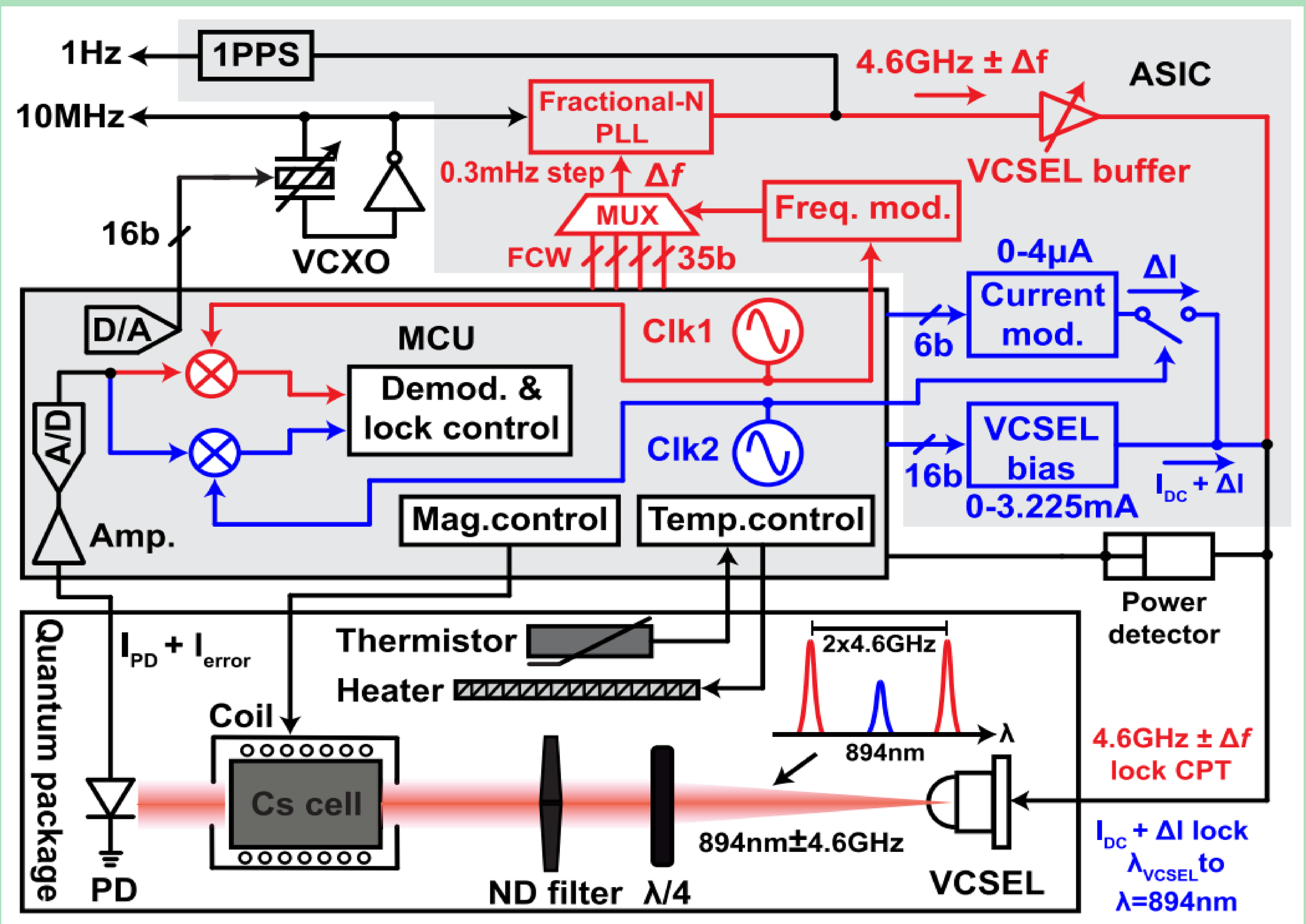

Figure 3. System structure

Quantum package:

- VCSEL (vertical cavity surface-emitting laser):

  VCSEL is a kind of semiconductor laser diode.

- λ/4 filter:

  λ/4 filter circularly polarize the laser light of the VCSEL.

- ND filter (neutral density filter):

  ND filter adjust the intensity of the VCSEL, so the absorption of the Cs atoms will not saturate because of the strong laser light.

- PD (photo detector):

  The PD current reflects the strength of light that passes the Cs atom cell.

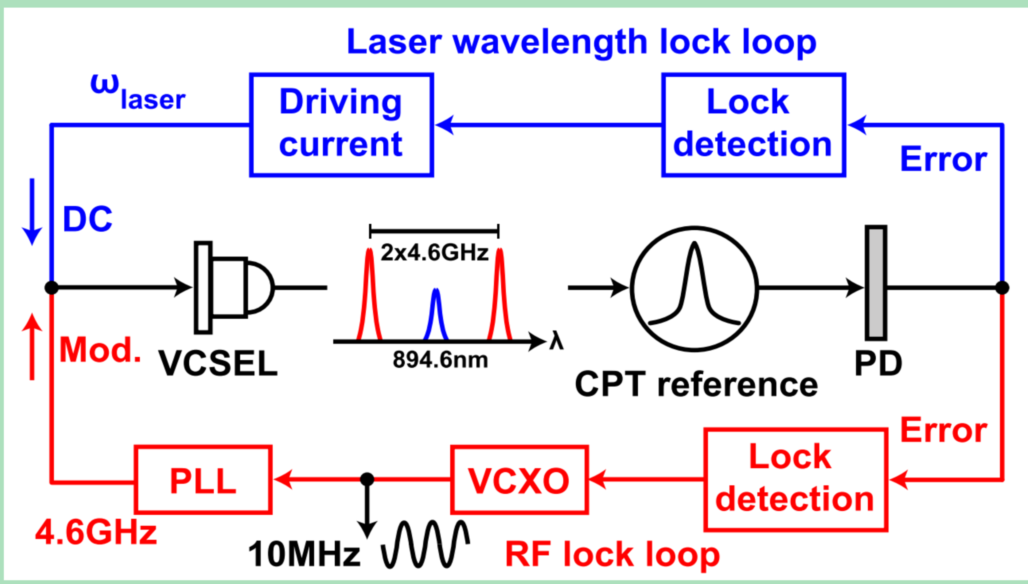

Figure 5. Wavelength locking loop and RF locking loop block diagram

Wavelength locking loop:

It generates the DC driving current for VCSEL and lock the wavelength of the VCSEL to 894.6 nm. The wavelength of the VCSEL has a linear relationship with the driving current. Sweep the driving current for the VCSEL, when the PD detect the maximum light absorption, the VCSEL wavelength reach the locking point.

RF locking loop:

A PLL is used to generate a current which does direct modulation to the VCSEL light. The direct modulation is a method to split the frequency of the light by modulating the laser driving current. When the frequency difference of the two light equals to the Cs ground state hyperfine frequency, the CPT phenomenon will be detected by the PD.

Reference:

[1] H. Zhang et al., "ULPAC: A Miniaturized Ultralow-Power Atomic Clock", IEEE Journal of Solid-State Circuits, vol. 54, no. 11, pp. 3135-3148, Nov. 2019