Active light shift suppression in CPT atomic clock

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Abstract: We demonstrated experimental implementation of coherent population trapping resonance phase-jump spectroscopy consisting of discrete phase modulation of the bichromatic pumping radiation frequency difference which allows error signal generation for the resonance active light shift elimination.

1. Introduction

The effect of coherent population trapping (CPT) is the foundation of the modern approach to development of miniaturised atomic clocks [1]. One of the main issues that limit performance of such devices is the existence of so-called light shift of the reference resonance. This effect is the principal physical mechanism, through which the long-term stability of the atomic clock may be degraded not only by fluctuations of the laser's output power, but also in the process of optical cell aging [3], since changes in the optical medium absorbance may also affect the amount of the field shift. In CPT-based atomic clocks, the resonance is excited by a multi-component field formed through phase modulation of single-frequency radiation resulting in spectral components with adjacent frequency difference equal to the modulation frequency. The resonance is excited by two components whose frequency difference is equal to the frequency of the hyperfine splitting of the ground state of an alkali metal atom (6.835 GHz for ^{87}Rb). Other pumping radiation components do not participate in resonance formation. They do affect, however, its frequency because of the AC Stark effect. The amount of shift depends on the distribution of spectral component amplitudes and is driven by the modulation depth. There exists a particular modulation depth index, at which the total field shift of the CPT resonance becomes zero [4]. The problem is that until recently, no methods were available that would allow detection and active suppression of the light shift of the CPT resonance in atomic clocks without additional requirements (such as radiation intensity modulation).

It has been experimentally proven that application of the phase-jump spectroscopy method [5] consisting in discrete phase modulation of the frequency difference of the pumping multi-component field makes it possible to synthesise an error signal by integration of the spectroscopic signal over a part of the modulation period and use it for detection of the field shift of the CPT resonance [6]. This work presents experimental implementation of a phase-jump spectroscopy method that proves applicability of this approach to active suppression of the light shift of the CPT resonance

2. Experiment

The experimental installation is schematically shown in Fig. 1a. The radiation source was a single-frequency distributed Bragg reflector (DBR) laser emitting at the wavelength of the D1 absorption line in ^{87}Rb. In order to create multi-component field, its radiation was phase-modulated with a resonant electro-optical modulator. The modulation frequency was ½ of the frequency of the hyperfine splitting of the rubidium ground state, and the resonance was created by the +1 and –1 spectral components. The phase of the RF signal fed into the modulator was modulated by a square signal with frequency of 250 Hz and duty cycle of 50%. The phase modulation amplitude was set to $\pi/2$ and corresponded to the best contrast of the spectroscopic signal. The CPT resonance was detected in the transmission spectrum with a photo-detector having a band-width of 1 MHz.

The signals from the photodetector and the square wave generator were digitised with a two-channel oscilloscope (Fig. 1b) for further mathematical processing. Following [6], as a first stage, the error signal was synthesised for frequency stabilisation to the CPT resonance. For this, the photo-detector signal was integrated over the entire modulation period, its part after the phase jump factored with the opposite sign. This signal has a dispersion shape and was used for frequency stabilisation.

The second error signal containing the information concerning the field shift was synthesised in a similar way. The difference was in that integration was carried over only a half instead of the whole period: specifically, the signal was integrated over ¼ of the period after the upward phase jump and then over another ¼ after the downward jump. The signal composed in this way depended on the phase modulation depth, which is governed by the RF signal power (Fig. 2a), this dependence crossing zero at the power level of ~12.2 dBm. The dependencies of the frequency upon modulation power at two different intensities of the optical radiation also cross each other at the same level (Fig. 2b). The point of intersection in the second plot corresponds to the phase modulation depth, at which the light shift was eliminated.

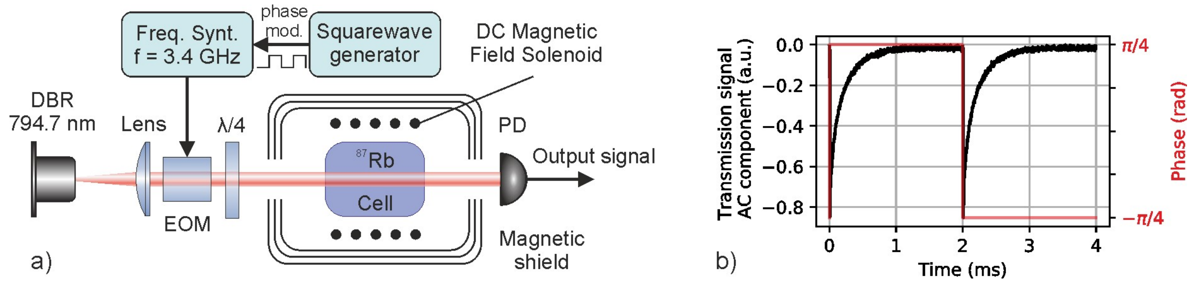

Fig. 1. a) Experimental setup: DBR – single frequency diode laser with distributed Bragg reflector, EOM – electro-optical phase modulator, λ/4 – quarter wavelength phase plate, PD – photodetector. b) PD output signal (black) and modulation signal (red)

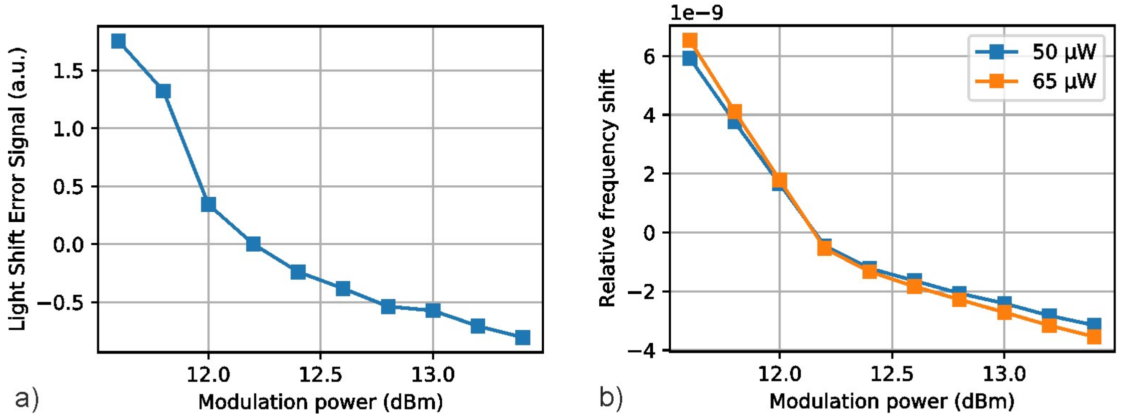

Fig. 2. Experimental dependencies from the power of modulating signal for a) - light shift error signal and b) - CPT resonance frequency with two outputs of radiation.

3. Conclusion

Hence, the results of the present work demonstrate that the error signal synthesised in phase-jump spectroscopy allows detection and active suppression of the CPT resonance light shift

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5. References

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