Specifics of using multifrequency pumping to register CPT resonances

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Abstract. When pumped by a diode laser, the injection current of which is modulated simultaneously by microwave and HF signals, CPT resonances are recorded in absorption, spaced from each other by an amount equal to half of the HF modulation frequency.

Keywords: CPT resonance, diode laser, frequency modulation.

1. Introduction

Since the creation of the first masers and lasers, continuous work has been carried out to improve the stability of quantum frequency standards [1]. Currently, rubidium clocks based on coherent population trapping (CPT) resonances are widely used [2, 3].

One of the main factors affecting the stability of frequency standards is light shift. The paper [4] describes a method for decreasing light shifts using multifrequency radiation of a femtosecond laser. In this case, the width of the emission spectrum significantly exceeds the value of the interval between optical transitions used for pumping CPT resonances. Also, most of the spectrum does not contribute to the pumping, which leads to a significant decrease in the signal-to-noise ratio. Moreover, other optical lines may be contained in wide spectrum of the femtosecond laser. Apparently, these facts are associated with the lack of successful experiments in this direction.

The spectrum matching condition is fulfilled in a diode laser with an external cavity, in which a multifrequency spectrum was realized with HF modulation of the injection current [6]. However, with this type of modulation, frequency adjustment is possible only by changing the cavity length, which is problematic [7]. It is quite simple to control the emission spectrum of a diode laser under the combined action of microwave and HF modulation of the injection current [8].

This paper presents the results of experiments on the registration of CPT resonances in the absorption in a cell with rubidium-87 under multifrequency pumping by a diode laser with an external cavity.
2. Experimental setup
We used a diode laser with an external cavity represented by a diffraction grating, the length of which was set in such a way that the intermode interval was close to half the frequency of the clock transition in rubidium (3.4 GHz). Schematic of the experimental setup is shown in figure 1.

HF (5) and microwave (6) modulation signals through an optical mixer (7) were fed to a diode laser with an external cavity (8). To eliminate feedback, a polarizer (9) and a quarter-wave plate (10) are installed in the path of the beam. Then, the radiation entered cell (11) with Rb-85 and Rb-87 vapors with the addition of 15 Torr Ne as a buffer gas. The transmitted radiation was recorded by a photodetector (12) connected to a digital oscilloscope (13). The scanning signal of the microwave modulation frequency was also fed to the oscilloscope for synchronization.

To record the fine structure of the spectrum, a heterodyne diode laser (2) was used, the length of the external cavity of which was scanned using a sawtooth voltage generator (1). The beats were recorded by a photodetector (3) connected to a digital oscilloscope (4). The signal of the sawtooth voltage generator was used for synchronization.

3. Experimental results and discussion
The emission spectrum of diode laser under the combined action of microwave (3.417 GHz, 16 dBm) and HF (17 MHz, 1 dBm) modulation is shown in figure 2.
It can be seen that at a modulation power of 1 dBm, each of the bands contains 5-8 HF components. A further increase in the HF modulation power leads to spectrum smearing. It should be noted that in each of the spectral bands, one of the HF components is absent in the central part due to the presence of amplitude modulation [9]. The resolution of HF components is limited by the bandwidth of the photodetector (2 MHz).

CPT resonances arise when the frequency difference between the interacting components is equal to the clock transition frequency. It is easy to show that the interval between CPT resonances is equal to half of HF modulation frequency [4].

When modulated radiation was passed through a cell with rubidium-87 vapor and a buffer gas, the structure of CPT resonances was detected, spaced from each other by half the HF modulation frequency (8.5 MHz). To record CPT resonances, the microwave modulation frequency was scanned with amplitude of 20 MHz, which leads to a change in the radiation power and the formation of a "pad" in the graph (figure 3).

![Figure 3. CPT resonances under microwave (black) and combined action of microwave and HF modulation (grey).](image)

For clarity, a gap is added along the ordinate axis. A decrease in the signal when using combined modulation can be associated with the influence of RF modulation on the optical frequency of radiation [7].

A well-known technique for eliminating slope is to construct a differential signal. In our case, a record from a digital oscilloscope is a set of pointwise values, which means that a differential signal can be plotted as an algebraic difference between adjacent points of the graph (figure 4).

![Figure 4. Derivative of CPT resonances with microwave modulation (a) and combined action of microwave and HF modulation (b).](image)
With the addition of RF modulation, the amplitude of the central resonance decreases, since the dependence of the amplitude of the resonance on the intensity of the interfering fields has a threshold character [10]. However, this can lead to a decrease in the light shift, since the total amount will include shifts from each of the resonances, some of which will have a negative value. The amplitudes of the side resonances are significantly less than the amplitude of the central one, which may be due to the fact that, with a limited spectrum, the contribution to the side resonances is made by a smaller number of pairs of components.

4. Conclusion
When pumped by a diode laser, the injection current of which is modulated simultaneously by microwave and HF signals, CPT resonances are recorded in the absorption, spaced from each other by an amount equal to half the HF modulation frequency. An increase of the resonance amplitude is possible due to an increase in the radiation power; however, for a diode laser with an external cavity, this leads to a shift in the optical frequency.

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