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CPT resonances under multifrequency pumping

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Abstract. **The possibility of detecting coherent population trapping (CPT) resonances with combined microwave and HF modulation of the injection current of a diode laser has been demonstrated for the first time. A series of resonances is observed, separated from each other by half the RF modulation frequency.**

Keywords: *CPT resonance, diode laser, frequency modulation.*

1. Introduction

Since the advent of first masers and lasers, work has been constantly 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 the light shift. Paper [4] describes a method for reducing light shifts using multifrequency radiation from a femtosecond laser. In this case, the width of the emission spectrum significantly exceeds the frequency interval between the optical transitions used to pump CPT resonances. Most of the spectrum in this case does not contribute to pumping, which leads to a significant decrease in the signal-to-noise ratio. Other optical lines can also fall into the wide spectrum of a femtosecond laser. Apparently, the absence of successful experiments in this direction is due to these facts.

The condition for matching the spectral width with the width of the optical transition is satisfied in a diode laser with an external cavity, in which a multifrequency spectrum was obtained with RF modulation of the injection current [5]. However, with this type of modulation, tuning the laser radiation frequency is possible only by changing the cavity length, which is problematic [6]. It is quite easy to control the emission spectrum of a diode laser under the combined action of microwave and RF modulation of the injection current [7].

In this paper, we present the results of experiments on the detection of absorption CPT resonances in a cell with ^{87}Rb under multifrequency pumping by radiation from an external cavity diode laser.

2. Experimental setup

The experimental setup is schematically shown in Fig. 1. We used a diode laser with an external cavity, the output mirror of which was a diffraction grating. The cavity length was chosen such that the intermode frequency separation was close to half the frequency of the clock transition in rubidium.

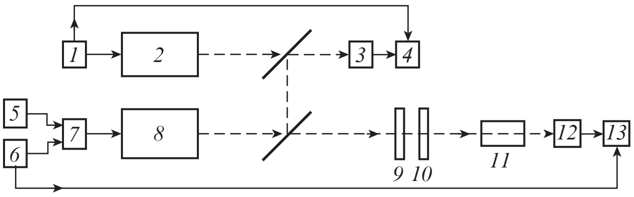

Figure 1. Scheme of the experimental setup:
(*1*) sawtooth voltage generator; (*2*) heterodyne diode laser; (*3, 12*) photodetectors; (*4, 13*) digital oscilloscopes; (*5*) source of RF signals; (*6*) source of microwave signals; (*7*) broadband mixer; (*8*) diode laser under study; (*9*) polariser; (*10*) quarter-wave plate; (*11*) cell with rubidium vapours. Dashed lines show optical connections, solid lines show electrical connections.

RF (*5*) and microwave (*6*) modulation signals were fed through a broadband mixer (*7*) to a diode laser with an external cavity (*8*). To eliminate feedback, a polariser (*9*) and a quarter-wave plate (*10*) were installed in the path of the laser beam. Radiation then entered a cell (*11*) filled with ^{85}Rb and ^{87}Rb vapours with the addition of Ne at a pressure of 15 Torr 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 synchronisation.

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

3. Experimental results

The pump source was a diode laser with a wavelength of 795 nm and a threshold current of 55 mA. The laser radiation frequency was chosen close to the frequency of optical transitions, which corresponded to an injection current of 75 mA. The frequency of the microwave generator was scanned around a value equal to half the frequency of the clock transi-

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tion (3.417 GHz). Additional frequency modulation at a frequency f_0 (9 MHz) made it possible to generate multi-frequency radiation.

The spectra of each of the side bands and the carrier band contain several RF components spaced from each other by the RF modulation frequency (Fig. 2). The asymmetry of the spectrum envelopes can be associated with the presence of amplitude modulation along with frequency modulation [8].

CPT resonances arise when the difference between the frequencies of the interacting components is equal to the frequency of the clock transition. It is easy to show that the frequency interval between CPT resonances is $f_0/2$ [4].

In the absence of HF modulation, the CPT resonance was recorded (Fig. 3a). The microwave modulation frequency was scanned with an amplitude of 5 MHz, which leads to a change in the radiation power and the formation of a pedestal in Fig. 3a. A well-known method for eliminating the slope of the curves is the formation of a differential signal. In our case, the signal from a digital oscilloscope is a set of points, which means that a differential signal can be obtained as the difference between the values at adjacent points (Fig. 3b). With additional RF modulation at a frequency of 9 MHz, the radi-

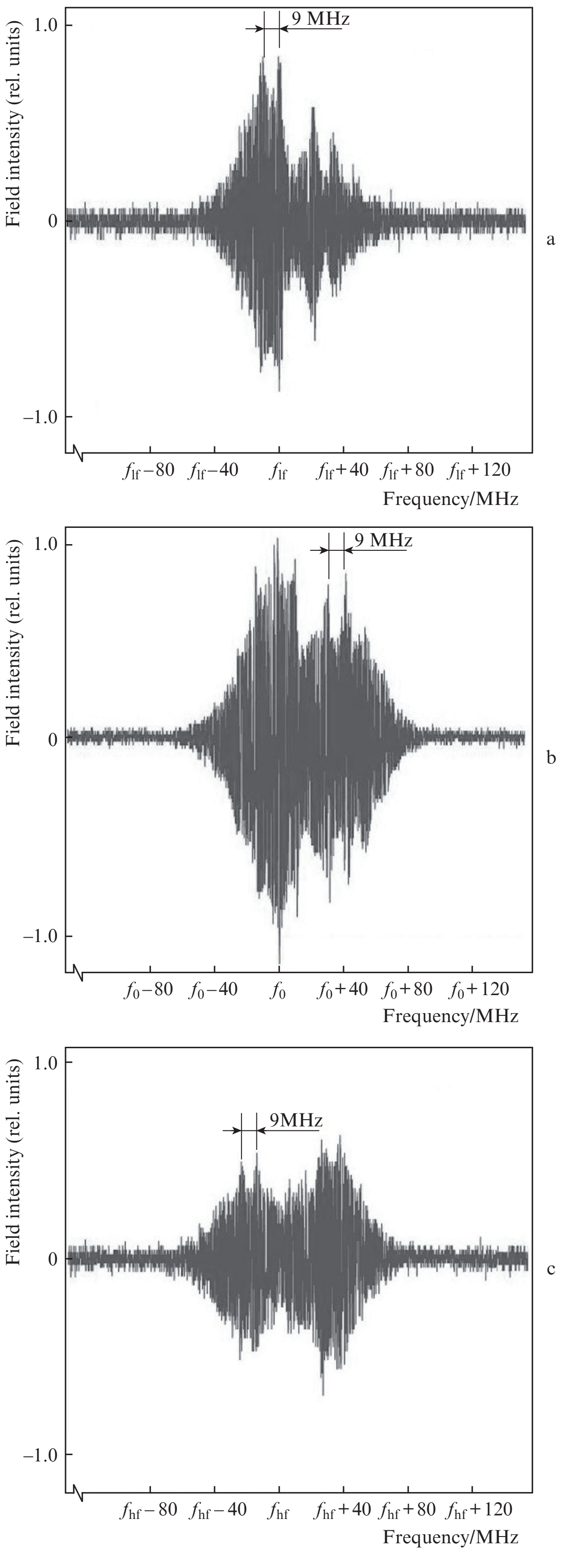

Figure 2. Emission spectra of (a) low-frequency, (b) carrier and (c) high-frequency bands under combined action of microwave (3.417 GHz, 16 dBm) and RF (9 MHz, −8 dBm) modulation.

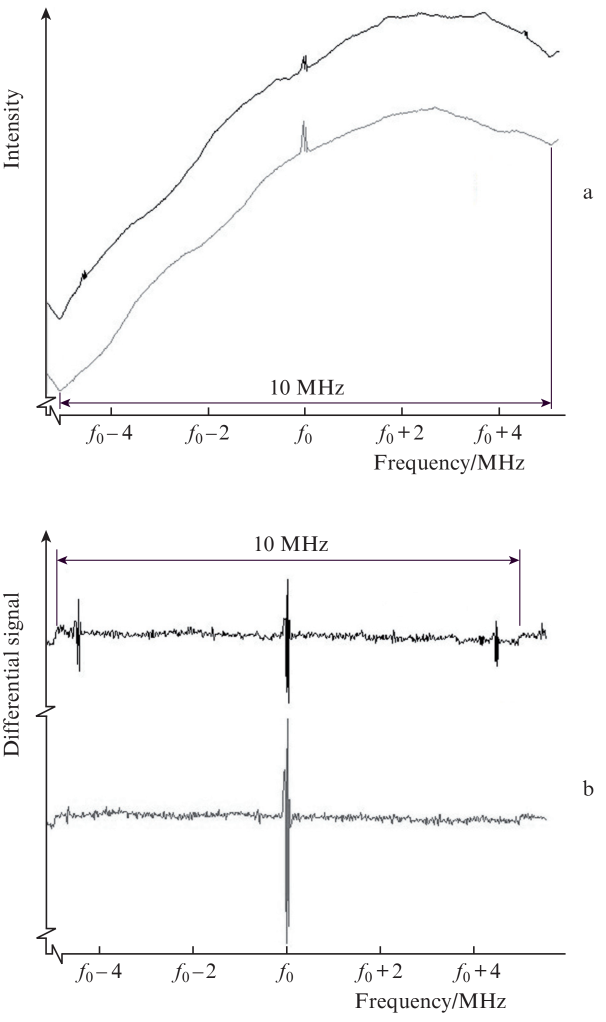

Figure 3. (a) Series of CPT resonances under multifrequency pumping and (b) a differential signal. Grey curves are signals for microwave modulation; black curves are for combined action of microwave and RF modulation (9 MHz, −8 dBm).

ation power increases by 1.5%. In this case, the amplitude of the central resonance decreases, since, in the general case, the dependence of the resonance amplitude on the intensity of the interfering fields has a threshold character [9]. The amplitudes of the spectral components decrease in inverse proportion to their number, which is important for reducing light shifts [4]. Two side resonances are also observed, which, as expected, are separated from the central one by the value $f_0/2$ equal to 4.5 MHz. The amplitudes of side resonances are much smaller than the amplitude of the central one. This may be because with a limited spectrum, the contribution to side resonances comes from a smaller number of pairs of components. Resonances with the maximum amplitude in this case are observed at a modulation power of −8 dBm; with its further increase, the amplitudes of all resonances decrease.

4. Conclusions

When atoms are pumped by radiation from a diode laser, the injection current of which is modulated simultaneously by microwave and RF signals, absorption CPT resonances are detected, separated from each other by half the frequency of the RF modulation. With additional RF modulation, the amplitudes of the resonances decrease, since the CPT effect has a threshold character, and the radiation power is redistributed over several components. An increase in the resonance amplitude is possible by increasing the pump power, but for a diode laser with an external cavity, this leads to a shift in the optical frequency relative to the centre of the absorption line.

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