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Quantum frequency standard

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Description

The present invention relates to a quantum frequency standards (QFS), devices for generating, amplification, modulation, demodulation or frequency conversion, and can be used as a means to increase the frequency stability.

The principle of operation is based on QFS crystal oscillator frequency stabilization of the atomic line of alkali metal. At the same time the nominal value of the frequency and systematic change in frequency with time is completely determined by the frequency and stability of the atomic line. Observation of resonance corresponding line splitting of the ground state is carried out in pairs of metal atoms contained in a special cell (the cell). The signal is usually observed resonance or fluorescence of alkali atoms in a cell, or a specific frequency of light transmittance through the cell. Golf irradiation cell creates a frequency-modulated radiation of one laser (or use two lasers whose frequency difference corresponds to the modulation of the resonance line splitting atoms). As a result, the modulation of the laser radiation in the spectrum appear side harmonics. When the distance between the first harmonic is a frequency microwave (MW) resonance, there is a coherent superposition of atomic states nonabsorbent and passing the cell grows. This effect is called coherent population trapping (CPT) or lambda resonance. The modulated laser radiation at a frequency of hyperfine resonance of metal atoms is applied to a cell containing a mixture of alkali metal vapor and a buffer gas. For example, this modulation of the laser can be obtained by modulating the microwave generator-managed source or new types of lasers with the necessary range of modulation of the radiation or laser radiation impact on the electro-optical modulator, or other elements capable of changing the phase of the optical radiation. In a cell containing a mixture of alkali metal vapor and a buffer gas, when the difference in frequency between sidebands ($\omega 21 = \omega 2-\omega 1$) or between the laser frequency ($\omega 21 = \omega 2-\omega 1$) is equal to the frequency of the microwave resonance, there is a narrow gap absorption modulated radiation laser. When exposed to the modulated laser radiation is an effective shift in the optical resonance picture. Laser radiation influences the width and frequency shift of the microwave resonance. This optical (field) shift is proportional to the intensity of the light field and essentially depends on the detuning of the optical frequency of the laser radiation in the optical resonance. At the exit of the cell can be observed two types of signal: fluorescence signal directly passed ("transmissive") through the cell laser radiation. When monitoring CPT resonance observed decrease in fluorescence signal, whereas the CPT-resonance "transmittance" of the laser radiation is detected by an increase in the transmission of the modulated laser radiation. This signal goes to the photodetector and subsequently observed directly by the recording apparatus either undergoes synchronous detection in order to distinguish the signal tuning frequency microwave generator is used to modulate the laser (or to maintain the difference frequency of the two lasers), to thereby implement QFS.

QFS known (Patent No: US 6,265,945, Date of Patent: Jul. 24, 2001) containing the laser optical output is connected through a quarter-wave plate with optical input cell. With cell blocks are also connected to produce a magnetic field in the cell and the cell temperature stabilization. Optical laser output is also connected to the optical input of the first, controlling the intensity of the laser photodetector. Electrical output of the photodetector is connected to the input of the first block of the analog-digital converter of the microcontroller. The first optical output cell connected to the optical input of the photodetector for recording the intensity modulated signal from the cell. Electrical output of the photodetector is connected to a second block of the analog-digital conversion of the microcontroller. The second optical output of the cell is connected to the optical input of the third photodetector, which controls the intensity of the fluorescence. Electrical output of the photodetector is connected to the third block of the analog-digital conversion of the microcontroller. The microcontroller provides the digital signal processing circuits, and the production of control signals by means of three digital to analog converters, for its outputs connected to three circuit blocks, and a control unit the temperature stabilization of the laser. Two outputs are connected to the inputs of the microwave generator and intended to control the frequency and modulation index of the output signal of the microwave oscillator. Third digital to analog output microcontroller is coupled to a first input of the laser power supply to control the optical frequency of the laser, by processing the photodetector signal from the microcontroller, which controls the intensity of fluorescence. Yield microwave generator connected to a second input of the power of the laser. Output power of the laser is coupled to an electrical input of the laser.

However, in this QFS used detection of the useful signal on the signal fluorescence and hence adjustment of the optical frequency of the laser to the optical resonance for a uniform spectral contours groups of atoms in the cell, and there are no measures to eliminate the field offset, which entails a relatively large error of alignment of the optical signal as a consequence, less accuracy in setting the resonance optical transition of a quantum frequency standard, less stable output frequency QFS.

Furthermore, it is known QFS (Patent No: US 6,320,472 B1, Date of Patent: Nov.20, 2001) is the prototype of the present invention and comprising a laser optical output is connected through a quarter-wave plate with optical input cell comprising a mixture of alkali metal vapors and buffer gas. With cell blocks are also connected to produce a magnetic field in the cell and the cell temperature stabilization. The first optical output cell connected to the optical input of said first photodetector for recording the intensity modulated signal from the cell. Electrical output of the photodetector is connected to the input of the first synchronous detector. The second input of the first synchronous detector connected to an output of the first modulator. Output of the first synchronous detector is coupled to a control signal generation of the microwave generator. Also, with the input of the generator is connected to the output of the first modulator. The output of the control signal generation of the microwave generator is connected to the input of the microwave oscillator. The output of the microwave generator is connected to the first control input of the power of the laser. The second optical output cell connected to the optical input of the second photodetector for registering the fluorescence intensity modulated signal from the cell. Electrical output of the photodetector is connected to the input of the second synchronous detector. The second synchronous detector generates a signal that is proportional to the signal correction to the optical frequency of the optical resonance line in the scheme within the CPT uniform contour of the resonance line. The second input of the second synchronous detector connected to an output of the second modulator. Also, with the release of the second generation unit is connected to the modulator control signal to the optical frequency of the laser power of the laser. The output of this unit is connected to a second control input of the power supply of the laser. Output power of the laser, which provides modulation of the laser radiation, and the management of its optical frequency, is connected to an electrical input of the laser.

However, in this optical device used to stabilize the laser frequency corresponding to the frequency of the transition from the excited state to the ground state P S alkali metal modulation at a low frequency DC component of the pump laser i0 corresponding to the center of the peak fluorescence. It uses a modulation control signal provided by the second modulator to 7 Hz. If the current component of the pump source is not exactly correspond to i0, the fluorescence signal, converted the second photodetector, the output is modulated by rectangular pulses. If a component of the current corresponds exactly to the pump source i0, the fluorescence signal, converted the second photodetector, the output will be a constant signal. Direct detection by the synchronous detector and the signal generator provides a power source control signal proportional to the detuning of the signal component of the current i0 from the pump, and this signal can be used to stabilize the optical frequency of the laser to maximum fluorescence. This feedback loop current component of the laser pump never stabilized to i0, and accordingly, the signal is not in the center of the contour of the fluorescence. The value of modulation, however, does not change much for not too strong optical frequency detuning of the laser compared to the width of the optical resonance. That is, using adjustment of the optical frequency of the laser at a uniform spectral contours groups of atoms in a cell, which entails a relatively large error of alignment of the optical signal, no compensation or reduction field shift, and as a consequence, less accurate setting into resonance of the optical transition of the quantum frequency standard and therefore less stable frequency output QFS.

The object of the invention is to increase the stability of the output frequency QFS.

The task is achieved by the fact that in the known device quantum frequency standard comprising a laser, an optical output coupled to the optical input of the cell, with the cell are also connected to units generating a magnetic field in the cell and the thermal stabilization of the cell, wherein the first optical output cell connected to the optical input of the first photodetector and an electric output of the first photodetector is connected to the input of the first synchronous detector, a second input coupled to the output of the first modulator, the output of which is connected to the input of the generator control signal to the microwave generator, which is connected to the output of the first synchronous detector, the output of generator control signal is coupled to an input managed microwave generator, the electrical output of the second photodetector is connected to the input of the second synchronous detector, a second input coupled to the output of the second modulator, whose output is connected to the input of the control signal of the optical frequency of the laser, outputs the microwave generator and the generator control signal is a current source connected to the inputs managed a current source whose output is connected to an electrical input of the laser according to the invention it includes a source of reference radiation, the second photo detector, a second synchronous detector, a second modulator driver control signal to the RF generator, with the RF generator and controlled microwave generator, on the optical output of the reference radiation and the laser output prototype connected to the optical input of the second administration of the photodetector, the electrical output of which is connected to the input of the second administration, a synchronous detector, a second input coupled to the output inputted second modulator, a second output of introducing a second modulator connected to a first input of the second inputted shaper control signal HF generator, a second input coupled to the output inputted second synchronous detector inputted generator control signal RF generator coupled to the first input of the inputted RF generator output inputted RF generator connected to a second input of a controlled current source, with the output of the generator a control signal generator connected to the microwave input inputted microwave oscillator, a first output inputted microwave generator connected first inputs of controllable current source, the second output inputted microwave generator is coupled with the entered RF generator.

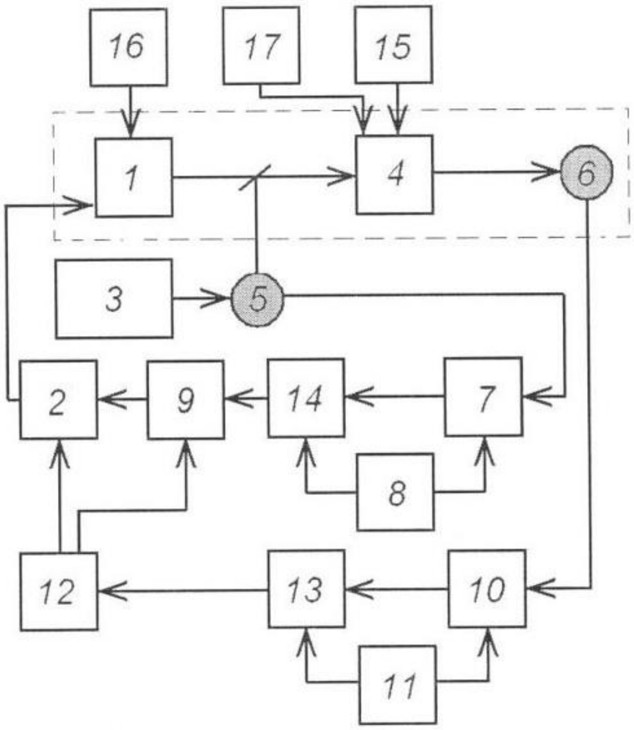
1 is a block diagram of QFS,

Figure 2 is a diagram of the working levels of alkali metal QFS,

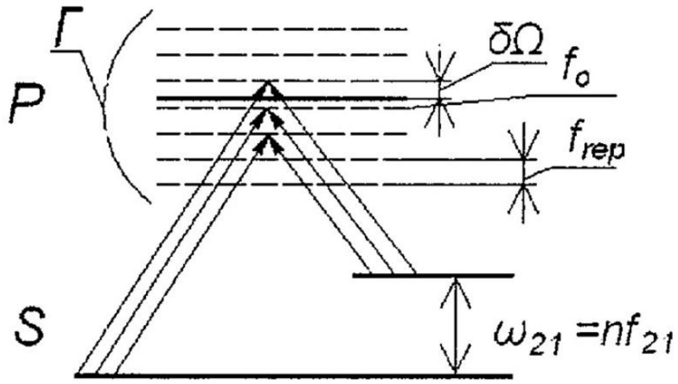
3 shows the dependence of the relative shift of the optical displacement harmonic ratio of the optical spectrum of the laser to the mode spacing of the spectrum.

QFS (1) comprises: 1 - laser, 2 - controlled current source of the pump laser 1, 3 - reference source of radiation, 4 - cell with alkali metal vapor and a buffer gas, 5 - photodetector 6 - photodetector 7 - synchronous detector 8 - modulator 9 - controllable HF generator, 10 - synchronous detector, 11 - modulator, 12 - controlled microwave generator, 13 - driver control signal to the microwave generator

12, 14 - driver control signal RF generator 9, 15 - magnetic field generating unit 4 in the cell, 16 - the temperature control of the laser system, 17 - temperature control system 4 cells.

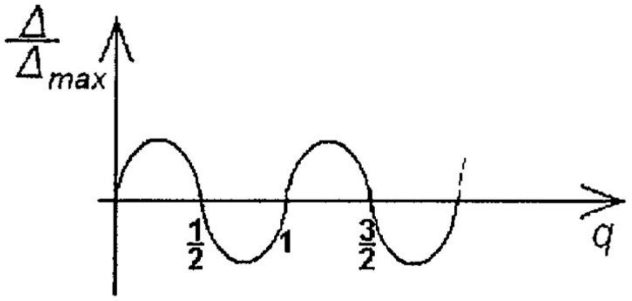


ФИГ.1



ФИГ.2

Thus the optical output of the laser 1 is connected to the optical input of the cell 4, cell 4 is also connected to block a magnetic field 15 in the cell 4 and the temperature control system 17, the optical output of the cell 4 is connected to the optical input of the photodetector 6 and the electrical output of the photodetector 6 is connected to the input synchronous detector 10, a second input coupled to the output of the modulator 11, the second output is connected to the input of the generator control signal 13, the microwave generator 12, a second input of the control signal 13 is connected to the output of the synchronous detector 10, the output of generator control signal 13 is connected to the input managed microwave generator 12. Part of the optical laser 1 is mixed in the optical input of the photodetector 5 with the reference optical radiation source 3. The electrical output of the photodetector 5 is connected to the input of a synchronous detector 7, a second input coupled to the output of the modulator 8, a second output connected to the input a control signal generator 14 RF generator 9, the output unit 14 is connected to the input of a controlled RF generator 9, the outputs of the microwave generator 12 and the unit 9 connected to the input of a controlled current source of the pump 2, whose output is connected to an electrical input of the laser 1.



ФИГ.3

The laser 1 may be configured as a semiconductor injection laser ILPI Thermorefrigerators-102 Peltier unit 2 may be an analog or tsifroupravlyaemy electronic power supply of the laser 1 as a reference radiation source 3 can be used with existing QFS field shifts or stable laser emitters with the frequency of the optical radiation equal to the frequency of the optical CPT resonance cell 4 may be a sealed quartz cavity with a characteristic size of 1 × 1 cm biasing solenoid vapor mixture with an alkali metal, e.g., 87Rb, and a buffer gas, e.g., N2, blocks 5 and 6 may be a high frequency photodetectors sensitivity lying in the range of optical frequencies of the laser, the blocks 7 and 10 can be synchronous detectors made with discrete components or, for example, on the basis of the chip K561KP1 and buffer amplifiers K544UD2 and filters based on them, Blocks 8 and 11 may be electrically quartz oscillators predetermined frequency modulation blocks 13 and 14 may be formed each in a repeater-based chip K561KP1 and buffer amplifiers K544UD2 or multiplier K174HA10 additional discrete elements, block 12 may be formed at controlled oscillator voltage (VCO) HMC836LP6CE unit 9 may be made, for example, on the discrete elements in the form of a voltage-controlled oscillator, the control unit 15, for example, may be a current source with a feedback loop based on the Hall sensor SS495A, blocks 16 and 17 may be DC is collected on the available discrete elements with a feedback loop based on the temperature sensor LM335M / NOPB.

The device operates as follows. Figure 1 QFS based CPT resonance uses a laser 1 with the spectrum of optical radiation in the form of a comb of frequencies equidistant from the central frequency f0 and the mode spacing frep, determined by the repetition rate of the laser. The line width of the optical resonance of G determined by the parameters and the type of laser. To achieve the detection of the frequency shift must enter position modulation modes of the optical spectrum which can be implemented in two ways:

1. Due to the position of the carrier frequency modulation of the optical spectrum without changing the distance between the components of the spectrum. For example, the center frequency of the optical spectrum modulated frequency F, and the distance between the modes of the spectrum must satisfy F << frep≈G (about the width D).

2. Due to the modulation of the distance between the equidistant components of the optical spectrum. For example, the center frequency f0 of the optical spectrum is not shifted, and the distance between the modes of the spectrum ranges frep≈G.

As a result of the irradiation cell 1 4 laser radiation with a spectrum of optical radiation in the form of a comb of equidistant frequency (repetition frequency frep) picture CPT resonance takes the form shown in Figure 2. There ω21 - the resonance frequency of the hyperfine splitting of the line of alkali atoms, which is obtained by multiplying the internal operating frequency f21 QFS in a number of times n. Since the laser light affects the frequency shift of the microwave resonance, a certain shift in the microwave resonance CIT, which is carried out by frequency tuning QFS. In this device, the resulting shift in the field - the amount of shifts of different pairs of events resulting from the creation of a specific set of optical frequencies, giving an effective contribution to the CPT-resonance. Their number can be estimated ratio, where T - the line width of the optical resonance, frep - the distance between the modes of the optical spectrum of the laser frequency. Since the magnitude of the optical shift Δn have different signs, averaged over the effective range of events, defined as a reduction will lead to a shift of the light. For a uniform laser emission spectrum, overlapping both electronic absorption lines can be written, where kn-kn-q - difference of the saturation parameters symmetric modes of the optical spectrum of the laser frequency, δΩ - shift of the optical spectrum of the laser relative to the center of the optical resonance. The value of Δ depends on frep, and from f0. Because it turns out that. The normalized field shift depending on the displacement of the optical spectrum of the laser to the mode spacing δΩ frep,, shown in Figure 3. Because of this dependence it can be seen that the modulation of the optical spectrum and further synchronous detection and management should focus on the zero values of this dependence that essentially achieved with integer proportional to the frequency f21 QFS frequency frep.

Claims (1)

1: Quantum frequency standard comprising a laser, an optical output coupled to the optical input of the cell, with the cell are also connected to units generating a magnetic field in the cell and the thermal stabilization of the cell, wherein the first optical output cell connected to the optical input of said first photodetector and an electric output of the first photodetector is connected to the input of the first a synchronous detector, a second input coupled to the output of the first modulator, the output of which is connected to the input of the generator control signal to the microwave generator, which is connected to the output of the first synchronous detector, the output of generator control signal is connected to the input of a controlled microwave generator, the electrical output of the second photodetector is connected with the input of the second synchronous detector, a second input coupled to the output of the second modulator, whose output is connected to the input of the control signal of the optical frequency of the laser, outputs the microwave generator and the generator control signal to the current source of the pump laser connected to the input of a controlled current source of the pump, whose output is connected an electrical input of the laser, characterized in that it includes a source of reference radiation, the second photo detector, a second synchronous detector, a second modulator driver control signal to the RF generator, with the RF generator and controlled microwave generator, wherein the optical output of the reference source of radiation and laser output coupled to the optical input of the second administration of the photodetector, the electrical output of which is connected to the input of the second administration, a synchronous detector, a second input coupled to the output inputted second modulator, a second output of introducing a second modulator connected to a first input of the second inputted generator control signal RF generator , the second input of which is connected to the output inputted second synchronous detector inputted generator control signal RF generator coupled to the first input of the inputted RF generator output inputted RF generator connected to a second input of a controlled current source, with the output of the generator control signal to the microwave generator coupled input inputted microwave oscillator, a first output inputted microwave generator connected first inputs of controllable current source, the second output inputted microwave generator is coupled with the entered RF generator.