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# QUANTUM FREQUENCY REFERENCE AT 3.39 μ WAVELENGTH

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A number of advantages of optical standards (references) over frequency standards in the radio band were pointed out in [1]. Until recently, however, the characteristics of optical standards were much inferior to quantum generators operating in the radio band, particularly, the reproducibility of the frequency of laser radiation was at best $\sim 1 \times 10^{-11}$ [2 - 4]. We report here the development and investigation of a laser which is not inferior in its frequency characteristics to the best frequency standards of the radio band.

The optical frequency standard is based on an He-Ne laser with an internal nonlinearly-absorbing methane cell [1 - 2]. A considerable increase of stability and reproducibility of the frequency was attained as a result of investigations of the optimization of the laser parameters. First, narrow and contrasty power peaks were obtained at the frequency of the vibrational-rotational transition $\nu_3[P(7)]$ of the CH$_4$ molecules by lowering the methane pressure in the cell to several millimeters, by choosing the intensity of the saturating field, and by greatly decreasing the resonator losses (the Q of the peak is $\sim 1 \times 10^9$ and the relative magnitude reaches 15 - 20% as against 2 - 3% in [2 - 4] . Second, the use of an amplifying laser tube with a special discharge-gap configuration [5] has greatly lowered the noise of the gas-discharge plasma. The "low-noise" amplifier tube consisted of a series of channels 9 cm long alternating with spheres of 3 cm diameter, and ensured suppression of the low-frequency noise in the laser radiation by an approximate factor of 250 compared with tubes of the usual construction. The high contrast of the peaks, the considerable reduction of the noise, and also the effective shielding of the generators against external acoustic, mechanical, and temperature disturbances have all made it possible to effect a highly accurate tuning of the laser generation frequency to the crest of the power peak.

The stability and reproducibility of the laser frequency was investigated with a setup consisting of two generators with absorbing cells, systems for tuning the laser frequency to the crest of the molecular resonance, and a laser heterodyne "coupled" with a 3-MHz shift to the frequency of one of the investigated generators. The radiation of each of the stabilized lasers was mixed independently with the heterodyne radiation. The time-synchronized measurement of the frequencies produced by optical heterodyning of two "beat" signals has made it possible to determine the magnitude and direction of the frequency shifts of the radiating lasers, eliminating by the same token the instability of the heterodyne frequency and the mutual influence of the generators on each other.

A typical plot of the fluctuations of the difference frequency for two independently stabilized generators is shown in Fig. 1. At an averaging time of 100 sec, in time intervals of several hours, the mean-squared frequency deviation of each generator from its mean value was 2.4 Hz, corresponding to an instability of $3 \times 10^{-14}$.

A study of the influence of the generator parameters and of its operating conditions on the frequency of the output radiation has shown that the most important factor limiting the reproducibility of the laser frequency is the

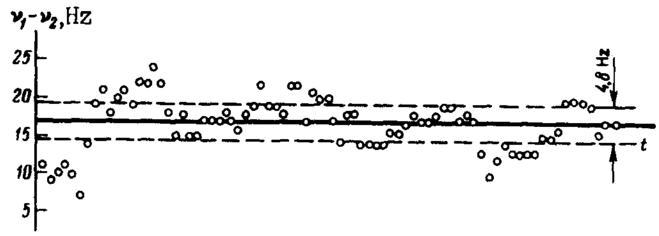

Fig. 1

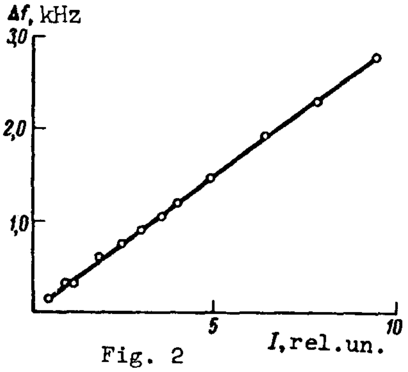

Fig. 2

Fig. 1. Plot of the difference frequency for two stabilized lasers. The sampling interval is 2 min.

Fig. 2. Dependence of the laser generation frequency on the field intensity in the resonator (in relative units).

dependence of the radiation frequency on the intensity of the saturating field. It has been established that for a wide range of saturation parameters $\sigma$ in methane, ranging from less than 1 to 10 - 12, the frequency shift follows a linear law (Fig. 2). Allowance for this dependence (extrapolation into the region of weaker fields, or else comparison of the generator frequencies at identical saturation parameters), has made it possible to obtain a laser frequency reproducibility accuracy of $\pm 5 \times 10^{-13}$.

The obtained values of the stability and reproducibility of the frequency of the laser radiation show that the considered type of laser is not inferior in its characteristics to the best radio-band frequency standards. One can hope that in the future the error of frequency reproduction of the unperturbed molecular transition in this laser will be reduced to $1 \times 10^{-13} - 5 \times 10^{-14}$. Indeed, our experiments have shown that the shift of the transition frequency in external constant magnetic and electric fields is very small. Thus, for example, application of an electric field up to 100 V/cm and a magnetic field up to 10 Oe to the methane cell does not lead to a noticeable shift of the frequency at a registration accuracy $3 \times 10^{-14}$. On the other hand, the frequency shift due to the collisions of the methane molecules with one another can be measured with the required degree of accuracy, or else practically eliminated in generators with a beam-type nonlinear absorbing cell [6].

In conclusion, we note that the considered quantum frequency standard can be used in experiments aimed at determining more accurately one of the fundamental physical constants, the velocity of light, and can be used in metrology to realize a unified standard for frequency, time, and length.

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