AN IMPROVED, OPTICALLY-PUMPED, PRIMARY FREQUENCY STANDARD

Atsushi Hasegawa, Kyoya Fukuda, Noboru Kotake, Masatoshi Kajita, and Takao Morikawa
Communications Research Laboratory, 4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184, Japan
and
W. D. Lee, Craig Nelson, D.A. Jennings, Lew Mullen, Jon H. Shirley, and R. Drullinger
NIST, Time and Frequency Div., 325 Broadway, Boulder CO USA

Abstract

An improved primary frequency standard based on an optically-pumped, thermal, atomic-beam has been jointly developed by CRL and NIST. The design details along with the first evaluation and comparison with NIST's existing standard are presented.

The Communications Research Laboratory (CRL) of Japan and the National Institute of Standards and Technology (NIST) of the US have collaborated on the development of an improved primary frequency standard based on an optically-pumped, thermal, atomic beam. The goal of this development has been a primary standard with an uncertainty limit at least equal to that of the existing NIST standard (5×10^{-15}) but with a more totally engineered system capable of nearly automated evaluations.

The atomic beam tube is functionally equivalent to that of the previously developed device known as NIST-7 [1]. The cavity is 1.55 m long and is terminated in De Marchi rings [2]. The C-field is generated by a shielded solenoid that extends over the entire length of the machine, including the optical state preparation and detection regions. The longitudinal field uniformity measured during assembly shows that the field at one end of the cavity differs from the mean by 5×10^{-4}. The measured field variations are essentially identical to those found in NIST-7 and are apparently a result of the current return lead for the solenoid rather than the fit of the shield end caps as previously thought. This field variation leads to a bias in the standard of about one part in 10^{15} but it can be evaluated a few parts in 10^{17}.

The diode laser system is based on a multi-electrode, distributed-Bragg-reflector (DBR) technology. This monolithic device is vastly less environmentally sensitive than the extended cavity diode laser systems that have been used on NIST-7.

The laser is frequency stabilized by an RF sideband technique [3] to a saturated absorption feature in an external, evacuated cesium cell. The multi-electrode nature of the laser allows the RF modulation to be added directly to the laser without causing AM which would bias the resulting lock point. This combination of the monolithic laser and RF sideband modulation scheme results in a laser system that is extremely robust, remaining locked indefinitely. The laser has a line-width of less than 1 MHZ and allows us to reach a detection limit of the shot noise in the atomic beam.

The RF synthesis is of a type that was previously developed at NIST [4]. It is capable of supporting a standard with short-term stability $\sigma_y(\tau) < 10^{-13} \tau^{-\frac{1}{2}}$ and long-term stability $\sigma_y(\tau) < 10^{-17}$. In this system, a high quality reference oscillator is multiplied up to near the atomic resonance and then a small, adjustable offset from a direct digital synthesizer (DDS) is mixed in to reach the atomic resonance. The system has the capability to lock a quartz local oscillator (LO) to the atomic resonance as in a normal, stand-alone atomic clock. However, we usually reference it to the "house maser" in which case the output of the standard is the recorded list of numbers sent to the DDS as the servo steers it to the atomic resonance.

The computer-controlled master operating system is written in C++ and uses object-oriented programing. This provides an extremely powerful and flexible platform that can be easily reconfigured as the specific hardware and/or needs of the controlling functions change. This clock operating system not only performs the function of the main frequency control servo, but it also evaluates and controls most of the significant terms in the error budget as well as recording and archiving all the data. It periodically monitors the Zeeman frequency and controls it by feedback to the C-field current, thus increasing the effective magnetic shielding by the gain of the servo system. It also monitors and controls the microwave power, thus stabilizing the second-order Doppler shift. During an evaluation cycle, this system (1) analyzes the velocity of the atomic beam by recording the Ramsey signal at several different microwave powers[5], (2)

analyzes cavity pulling, the effect of magnetic field inhomogeneity and Rabi line overlap shifts by recording the offset between each Ramsey line and its corresponding Rabi pedestal across the entire Zeeman spectrum[6], (3) looks with a sensitivity of a few parts in 10^{15} for any bias term that has dependence on microwave power and (4) with a sensitivity of several parts in 10^{15}, looks for any bias terms that result from an extraneous signal synchronous with the modulation.

The talk will give the results of the first evaluations of the new standard and comparisons of it to NIST-7.

References

[1]   See Robert E. Drullinger, David J. Glaze, J. P. Lowe, and Jon Shirley, "The NIST Optically Pumped Cesium Frequency Standard," IEEE Trans. Instrum. Meas., Vol. 40, No. 2, pp. 162-164, April 1991, and references cited therein.

[2]   Andrea De Marchi, Jon Shirley, David J. Glaze and Robert Drullinger, "A New Cavity Configuration for Cesium Beam Primary Frequency Standards," IEEE Trans. Instrum. Meas., Vol. 37, No. 2, pp. 185-190, June 1988.

[3]   J.L. Hall, L. Hollberg, T. Baer, and H.G. Robinson, "Optical heterodyne saturation spectroscopy," Appl. Phys. Lett., Vol. 39, No. 9, pp. 680-682, November 1981.

[4]   J.F. Garcia Nava, F.L. Walls, J.H. Shirley, W.D. Lee, and M.C. Delgado Aramburo, "Environmental Effects in Frequency Synthesizers for Passive Frequency Standards," in proc. 1996 IEEE International Frequency Control Symposium, pp. 973-979, June 1996.

[5]   Jon H. Shirley, "Velocity Distributions Calculated from the Fourier Transforms of Ramsey Lineshapes," IEEE Trans. Instrum. Meas., Vol. 46, No. 2, pp. 117-121, April 1997.

[6]   Jon H. Shirley, W.D. Lee, G.D. Rovera, and R.E. Drullinger, "Rabi Pedestal Shifts as a Diagnostic Tool in Primary Frequency Standards," IEEE Trans. Instrum. Meas. Vol. 44, No. 2, pp. 136-139, April 1995.