Physical Sciences

Correction for Self-Heating When Using Thermometers as Heaters in Precision Control Applications

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In precision control applications, thermometers have temperature-dependent electrical resistance with germanium or other semiconductor material thermistors, diodes, metal film and wire, or carbon film resistors. Because resistance readout requires excitation current flowing through the sensor, there is always ohmic heating that leads to a temperature difference between the sensing element and the monitored object.

In this work, a thermistor can be operated as a thermometer and a heater, simultaneously, by continuously measuring the excitation current and the corresponding voltage. This work involves a method of temperature readout where the temperature offset due to self-heating is subtracted exactly.

The true temperature of an object is $T_{object} = T_{sensor} - I \times V \times K$, where $I \times V$ (measured current times the measured voltage) is the power dissipated in the sensor, and K is the thermal resistance. Because the relation between the sensor electrical resistance and its temperature is typically not approximated well by a single simple function over a wide temperature range, and because the thermal impedance is often temperature dependent, this solution is only easily implemented in hardware for thermistors mounted with small thermal resistance, and operating in a narrow range of set points. A software implementation is possible for a wider range of conditions, but a prior mapping of thermal resistance vs. temperature is needed.

This work was done by Konstantin Penanen, Michael E. Ressler, Hyung J. Cho, and Kalyani G. Sukhatme of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-46894

Gravitational Wave Detection With Single-Laser Atom Interferometers

This technique has applications in other gravity and inertial force measurements.

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A new design for a broadband detector of gravitational radiation relies on two atom interferometers separated by a distance L. In this scheme, only one arm and one laser are used for operating the two atom interferometers. The innovation here involves the fact that the atoms in the atom interferometers are not only considered as perfect test masses, but also as highly stable clocks. Atomic coherence is intrinsically stable, and can be many orders of magnitude more stable than a laser.

Consider a detector configuration with two ensembles of atoms separated by a distance L, in which only a single laser beam is used to operate them. The laser interrogates the atoms similarly to how a local oscillator laser interacts with atoms in an optical clock. The results give the phase differences between the laser and the highly coherent atomic internal oscillations. As the laser phase fluctuations enter into the responses of the two phase difference measurements at times separated by the one-way-light-time, L (units in which the speed of light $c = 1$), it can be shown that the laser phase fluctuations can be exactly cancelled (while retaining the gravitational wave signal) by applying time-delay interferometry (TDI) to the phase measurement data.

The fundamental limitation of a one-arm Doppler measurement configuration (such as that of interplanetary spacecraft tracking experiments) is determined by the frequency stability of the "clock" that defines the frequency of the electromagnetic link. The most stable clocks are presently optical atomic clocks, which have shown stabilities of about 10^{-17} over 1,000-second integration time. This is accomplished by frequency-locking a highly stabilized laser to an atomic transition as an ideal passive frequency standard. The intrinsic atomic coherence is only limited by its natural lifetime. External perturbations cause additional frequency fluctuations, which may be controlled to a level of 10^{-18} and lower. These considerations imply that atoms might be used directly as ideal local reference oscillators for gravitational wave detection.

One of the key requirements in interferometric gravitational wave experiments is for the local reference frames to be as inertially free as possible. This is to reduce any non-gravitational forces and local gravitational disturbances that can cause changes in the laser phase. Ground-based interferometers achieve a high level of seismic isolation of their mirrors by using either passive or active isolation systems. Space-based detectors instead, such as LISA (Laser Interferometer Space Antenna), achieve inertial isolation by using highly sophisticated drag-free test masses. Although, in principle, one could trap atoms in such test masses, it is more practical to rely on laser-cooled atoms in ultra-high vacuum as alternative drag-free test masses, and to directly use them as reference sensors.

This work was done by Nan Yu and Massimo Tinto of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47334