



## Physical Sciences

### **Recirculation of Laser Power in an Atomic Fountain**

**Optical and electronic subsystems of a frequency standard can be simplified.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A new technique for laser-cooling atoms in a cesium atomic fountain frequency standard relies on recirculation of laser light through the atom-collection region of the fountain. The recirculation, accomplished by means of reflections from multiple fixed beam-splitter cubes, is such that each of two laser beams makes three passes. As described below, this recirculation scheme offers several advantages over prior designs, including simplification of the laser system, greater optical power throughput, fewer optical and electrical connections, and simplification of beam power balancing.

A typical laser-cooled cesium fountain requires the use of six laser beams arranged as three orthogonal pairs of counter-propagating beams to decelerate the atoms and hold them in a three-dimensional optical trap in vacuum. Typically, these trapping/cooling beams are linearly polarized and are positioned

and oriented so that (1) counter-propagating beams in each pair have opposite linear polarizations and (2) three of the six orthogonal beams have the sum of their propagation directions pointing up, while the other three have the sum of their propagation directions pointing down.

In a typical prior design, two lasers are used — one to generate the three “up” beams, the other to generate the three “down” beams. For this purpose, the output of each laser is split three ways, then the resulting six beams are delivered to the vacuum system, independently of each other, via optical fibers.

The present recirculating design also requires two lasers, but the beams are not split before delivery. Instead, only one “up” beam and one oppositely polarized “down” beam are delivered to the vacuum system, and each of these beams is sent through the collection region three times. The polarization of each beam on

each pass through the collection region is set up to yield the same combination of polarization and propagation directions as described above.

In comparison with the prior design, the present recirculating design utilizes the available laser light more efficiently, making it possible to trap more atoms at a given laser power or the same number of atoms at a lower laser power. The present design is also simpler in that it requires fewer optical fibers, fiber couplings, and collimators, and fewer photodiodes for monitoring beam powers. Additionally, the present design alleviates the difficulty of maintaining constant ratios among power levels of the beams within each “up” or “down” triplet.

*This work was done by Daphna G. Enzer, William M. Klipstein, and James D. Moore of NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).  
NPO-41202*

### **Simplified Generation of High-Angular-Momentum Light Beams**

**Inherent properties of a WGM resonator and optical fiber are exploited.**

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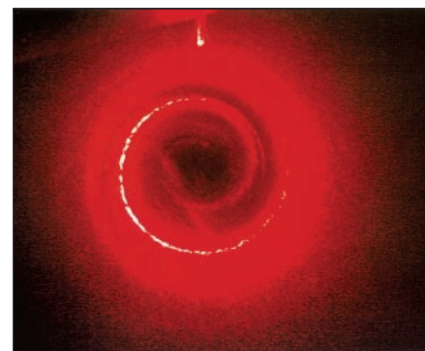
A simplified method of generating a beam of light having a relatively high value of angular momentum (see figure) involves the use of a compact apparatus consisting mainly of a laser, a whispering-gallery-mode (WGM) resonator, and optical fibers. The method also can be used to generate a Bessel beam. (“Bessel beam” denotes a member of a class of non-diffracting beams, so named because their amplitudes are proportional to Bessel functions of the radii from their central axes. High-order Bessel beams can have high values of angular momentum.)

High-angular-momentum light beams are used in some applications in biology and nanotechnology, wherein they are known for their ability to apply torque to make microscopic objects rotate.

High-angular-momentum light beams could also be used to increase bandwidths of fiber-optic communication systems. The present simplified method of generating a high-angular-momentum light beam was conceived as an alternative to prior such methods, which are complicated and require optical setups that include, variously, holograms, modulating Fabry-Perot cavities, or special microstructures.

The present simplified method exploits a combination of the complex structure of the electromagnetic field inside a WGM resonator, total internal reflection in the WGM resonator, and the electromagnetic modes supported by an optical fiber. The optical fiber used to extract light from the WGM resonator is made of fused quartz. The out-

put end of this fiber is polished flat and perpendicular to the fiber axis. The input end of this fiber is cut on a slant and placed very close to the WGM resonator at an appropriate position and



A **Vortex** is shown as it is generated by the apparatus. The red glowing stick at the top edge of the photo is a fused silica horn.