are determined by the relative proportions of N_2 and O_2 as measured or calculated by independent means. (The independent means could be measurements of vibrational Raman spectra of N_2 and O_2 or a chemical-equilibrium calculation.) Finally, the measured W_d is inserted into the blended conversion formula, yielding the temperature.

This work was done by Quang-Viet Nguyen of Glenn Research Center and Jun Kojima of Ohio Aerospace Institute.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18100-1.

Temperature Sensors Based on WGM Optical Resonators

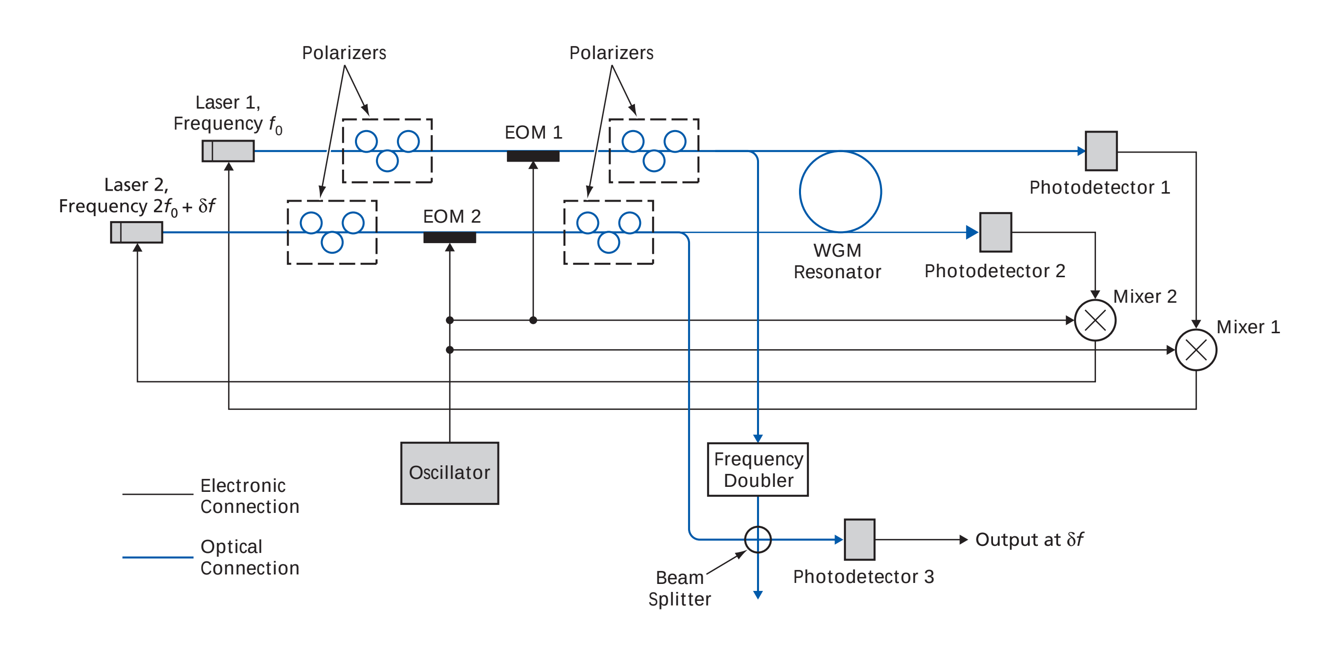
Differences between temperature-dependent frequencies of resonances would be measured.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed technique for measuring temperature would exploit differences between the temperature dependences of the frequencies of two different electromagnetic modes of a whispering-gallery-mode (WGM) optical resonator. An apparatus based on this technique was originally intended to be part of a control system for stabilizing a laser frequency in the face of temperature fluctuations. When suitably calibrated, apparatuses based on this technique could also serve as precise temperature sensors for purposes other than stabilization of lasers.

A sensor according to the proposal would include (1) a transparent WGM dielectric resonator having at least two different sets of modes characterized by different thermo-optical constants and (2) optoelectronic instrumentation for measuring the difference between the temperature-dependent shifts of the resonance frequencies of the two sets of modes. The figure schematically depicts an example of such a sensor. Laser 1, operating at frequency f_0, would be locked to a mode in the first of the two sets of WGM modes to be exploited; the mode locking would be accomplished by established means that would include photodetector 1, an oscillator, polarizers, mixer 1, and electro-optical modulator EOM 1. Laser 2, operating at frequency $2f_0 + \delta f$, would be locked to a mode in the second of the two sets of WGM modes to be exploited; in this case, the mode locking would be accomplished by established means that would include photodetector 2, the oscillator, mixer 1, and electro-optical modulator EOM 2.

Part of the modulated output of laser 1 would be fed through a frequency doubler to obtain a modulated beam at frequency $2f_0$. In a beam splitter, the $2f_0$ output from the frequency doubler would be combined with part of the modulated output of laser 2 at $2f_0 + \delta f$. The interference between these combined beams would cause the output of photodetector 3 to include a component at the heterodyne frequency, δf, which would have the desired temperature dependence. Inasmuch as f_0 and δf could readily be chosen to place δf within a suitable radio-frequency range and means for measuring radio frequency precisely are readily available, it would be straightforward to measure δf. Then the temperature could be calculated by inversion of the known temperature dependence of δf. It has been estimated that for a typical CaF_2 WGM resonator having a resonance quality factor (Q) of 2×10^{10}, the temperature-measurement sensitivity would be characterized by a temperature increment of about 40 μK for a frequency increment



The **Lasers Would Be Mode-Locked** to resonance frequencies f_0 and $2f_0 + \delta f$, respectively, of the WGM resonator. The heterodyne frequency, δf, would vary with temperature and, therefore, would be measured for use as an indication of temperature.

of half the width of one of the resonance spectral peaks.

This work was done by Anatoliy Savchenkov, Nan Yu, Lute Maleki, Vladimir Iltchenko, Andrey Matsko, and Dmitry Strekalov of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office–JPL. Refer to NPO-44469.

Varying the Divergence of Multiple Parallel Laser Beams

Lenses mode-matched to the laser beams would be moved axially within an afocal optical subassembly.

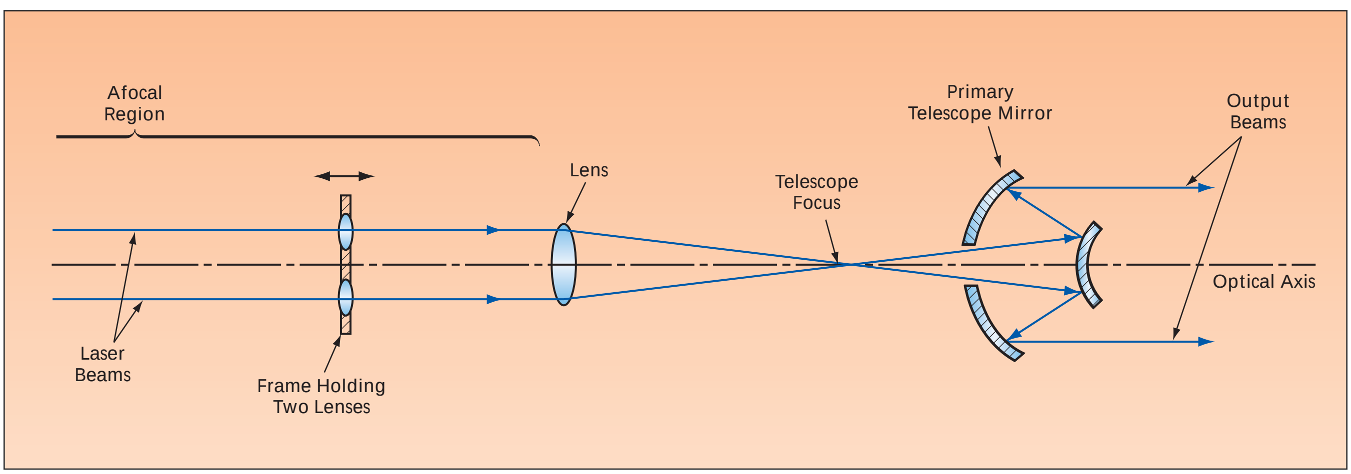
NASA's Jet Propulsion Laboratory, Pasadena, California

A provision for controlled variation of the divergence of a laser beam or of multiple parallel laser beams has been incorporated into the design of a conceptual free-space optical-communication station from which the transmitted laser beam(s) would be launched via a telescope. The original purpose to be served by this provision was to enable optimization, under various atmospheric optical conditions, of the divergence of a laser beam or beams transmitted from a ground station to a spacecraft. Beyond the original purpose, the underlying design concept could be beneficial for terrestrial free-space laser communication, ranging, and scientific instrumentation applications in which there are requirements to vary the divergences of laser beams.

In order to be able to provide for controlled variation of beam divergence, one must first gain detailed understanding of the optical train from each laser to the primary mirror of the telescope. Gaussian propagation of each laser beam through all the optical elements must be computed. If multiple parallel beams were to be transmitted, then by means of previously developed optics, they would be positioned symmetrically about the optical axis. It would be necessary to perform paraxial ray tracing to ensure that the beams emerging from the primary mirror into free space were parallel to each other and to the main optical axis of the telescope.

The design concept reflects a requirement in the original application that final divergence of the beam(s) propagating out from the primary mirror into free space be varied by moving only one lens or lens assembly in the optical train and that this motion not cause the outgoing beam(s) to deviate from parallelism with the optical axis. To satisfy this requirement, the telescope would incorporate an afocal optical subassembly, within which either a single on-axis lens in the case of a single laser beam or a ring assembly of lenses in the case of multiple laser beams (see figure) would be moved. The lens or lenses must be designed to mode-match the laser output through the afocal subassembly and telescope optics to produce the required beam divergence. By moving this lens (or moving the assembly of lenses as a single unit) along the optical axis, one would cause the divergence of the outgoing laser beam(s) to vary through the required range. Care must be taken to ensure that there is no apodization or vignetting through any limiting apertures in the overall optical system and that power density of any laser beam must not be so high as to result in dielectric breakdown of air or in damage to any optic along the optical path.

This work was done by Joseph M. Kovalik and Malcolm W. Wright of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-43967



A **Frame Would Hold Lenses** placed symmetrically about the optical axis to intercept multiple laser beams parallel to the axis. (For simplicity, only two beams are shown here, but the original design calls for eight beams). The frame would be moved along the optical axis to vary the divergence of the laser beams emerging from the primary telescope mirror. The motion of the frame and lenses would not cause the beams to deviate from parallelism with the optical axis.