of O_2 and O_3 gases is generated at the anode and H_2 is generated at the cathode. Some of the O_3 generated at the anode becomes dissolved in the water. The proportion of O_3 in the O_2/O_3 mixture can be maximized by the selection of suitable electrode materials and the use of a high overpotential. Although the proton-exchange membrane conducts protons, it does not conduct electrons. It is also impermeable by gases; consequently, it maintains separation between the O_2/O_3 mixture evolved at the anode and the H_2 evolved at the cathode.

Water circulates upward through the anode and cathode compartments of the stack of electrolytic cells. Water from the bottom of an anode and a cathode reservoir is gravity-fed to the bottom inlet of the anode and cathode compartment, respectively. From the tops of the anode compartments, the mixture of water and O_2 and O_3 gases and water containing dissolved ozone can flow freely upward, through a standpipe that ends in the anode reservoir, and from the tops of the cathode compartments, the mixture of water and H_2 gas can flow freely upward, through standpipe that ends in the cathode reservoir. The reservoirs double as liquid/gas separators: O_2 and O_3 diffuse out of the water in the anode reservoir,

are collected at the top of the reservoir, and are either vented or sent to an ozone-consuming process. Similarly, H_2 diffuses out of the water in the cathode reservoir, is collected at the top of that reservoir, and can be flared, vented, or sent to an H_2-consuming process.

As water is consumed in electrolysis and/or withdrawn from the anode reservoir for external use, makeup water (which must be deionized) is supplied to the system. The addition of makeup water and the circulation of water between the anode and cathode plumbing subsystems is controlled to maintain the desired levels of water in the reservoirs. The control subsystem responds to measurements by high- and low-water-level sensors in the reservoirs and exerts control via several solenoid shutoff valves and a transfer pump. The makeup water can be potable water, in which case it is preferable to introduce a secondary recirculation loop that purifies the water circulated through the cathode compartments and reservoir. Typically, such a recirculation loop includes a recirculation pump in series with a carbon-filter bed followed by an ion-exchange-resin bed.

The system operates with pressures high enough to maintain desired high concentrations of dissolved ozone: The

reservoirs and electrolytic cells are preferably designed to operate at gauge pressures up to about 30 psi ($\approx$0.2 MPa). Makeup water is conveniently supplied at a gauge pressure of about 50 psi ($\approx$0.35 MPa): the supply pressure must exceed the reservoir pressure in order to make the water flow into the reservoirs.

A refrigeration subsystem includes a compressor, a condenser, and a cooling tube coiled within the cathode reservoir. This subsystem removes the heat introduced by electrolysis and maintains the water in the system at or below a set temperature, which is typically about 35 °C: This is an important function because lowering the temperature extends the lifetime of the ozone dissolved in the water.

Interferometer for Measuring Displacement to Within 20 pm

Errors are reduced by suppressing effects of polarization leakage and thermal expansion.
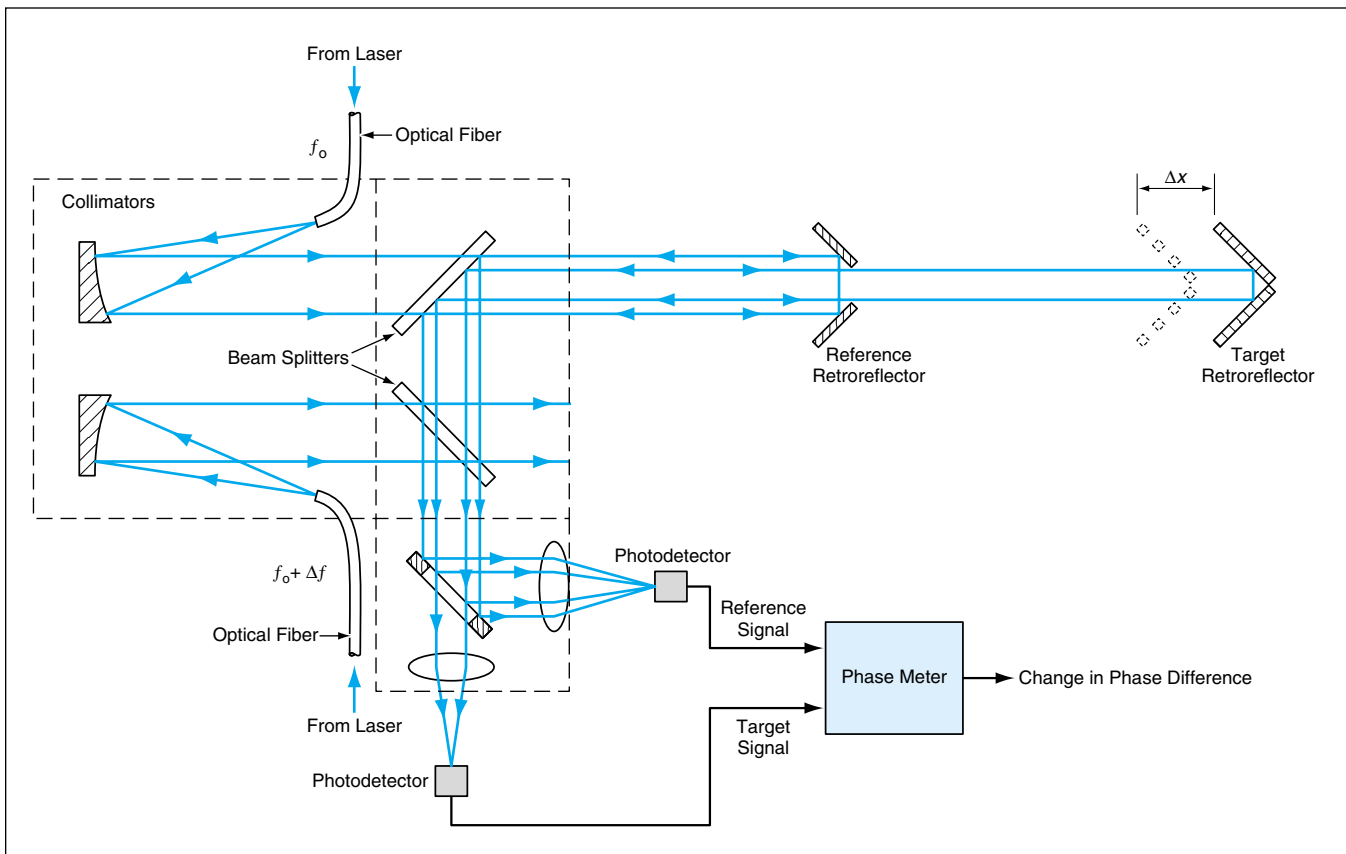
NASA's Jet Propulsion Laboratory, Pasadena, California

An optical heterodyne interferometer that can be used to measure linear displacements with an error $\leq$20 pm has been developed. The remarkable accuracy of this interferometer is achieved through a design that includes (1) a wavefront split that reduces (relative to amplitude splits used in other interferometers) self interference and (2) a common-optical-path configuration that affords common-mode cancellation of the interference effects of thermal-expansion changes in optical-path lengths.

The most popular method of displacement-measuring interferometry involves two beams, the polarizations of which are meant to be kept orthogonal upstream of the final interference location, where the difference between the phases of the two beams is measured. Polarization leakages (deviations from the

desired perfect orthogonality) contaminate the phase measurement with periodic nonlinear errors. In commercial interferometers, these phase-measurement errors result in displacement errors in the approximate range of 1 to 10 nm. Moreover, because prior interferometers lack compensation for thermal-expansion changes in optical-path lengths, they are subject to additional displacement errors characterized by a temperature sensitivity of about 100 nm/K. Because the present interferometer does not utilize polarization in the separation and combination of the two interfering beams and because of the common-mode cancellation of thermal-expansion effects, the periodic nonlinear errors and the sensitivity to temperature changes are much smaller than in other interferometers.

The present interferometer (see figure) makes use of two stable, collimated laser beams — one at a frequency of f_0, the other at the slightly different frequency of $f_0+\delta f$. The f_0 wavefront is split into two or more sections by a retroreflective reference device that could be, for example, a truncated corner-cube reflector or a mirror with holes. The portion of the f_0 wavefront reflected by the reference device serves as reference wavefront. The portion of the f_0 wavefront not reflected by the reference device is directed to a target in the form of a retroreflector. The target is mounted on the object, the displacement of which one seeks to measure relative to the reference device.

The light reflected by the target travels back through the optical system alongside the retroreflected reference light. Along the way, both the target

This **Heterodyne Interferometer** is used to measure the displacement Δx. In addition to the advantages mentioned in the main text, this interferometer contains fewer parts and can be fabricated with looser tolerances, relative to a typical prior interferometer designed for performing the same measurement.

and reference light beams pass through a beam splitter where the $f_0+\delta f$ beam is superimposed upon them. Then by use of truncated mirrors and lenses, (1) the target signal and part of the $f_0+\delta f$ signal are sent to one photodetector while (2) the reference signal and part of the $f_0+\delta f$ signal are sent to another photodetector. The lowest-frequency components of the heterodyne outputs of the two photodetectors are signals of frequency δf, the difference between the phases of

which is proportional to the amount by which the length of the target path exceeds that of the reference path. Any displacement Δx, of the target along the optical path results in a proportional change in this phase difference. Hence, measurement of the phase difference and of any change in the phase difference yields information on the displacement. One can calculate the displacement by use of the equation

$$\Delta x = \lambda\Delta\phi/4\pi,$$

where λ is the wavelength of the laser

light and $\Delta\phi$ is the change in the phase difference.

This work was done by Feng Zhao 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; (818) 354-7770. Refer to NPO-21221.

UV-Enhanced IR Raman System for Identifying Biohazards

UV pumping would increase IR Raman emissions.

NASA's Jet Propulsion Laboratory, Pasadena, California

An instrumentation system that would include an ultraviolet (UV) laser or light-emitting diode, an infrared (IR) laser, and the equivalent of an IR Raman spectrometer has been proposed to enable noncontact identification of hazardous biological agents and chemicals. In prior research, IR Raman scattering had shown promise as a means of such identification, except that the Raman-scat-

tered light was often found to be too weak to be detected or to enable unambiguous identification in practical applications. The proposed system (see Figure 1) would utilize UV illumination as part of a two-level optical-pumping scheme to intensify the Raman signal sufficiently to enable positive identification.

The UV and IR lasers would share common reflective optics and would il-

luminate a target simultaneously. The spectrum of IR Raman-scattered light emitted by the target would be characteristic of the target material and could therefore be used to identify the material, provided that the Raman signal was strong enough. The Raman-scattered IR light from the target would be collected and directed through a wavelength-dispersive optical element or,